NUCLEAR ENGINEERING

VOL. I NO. 6 SEPTEMBER, 1956

PRINCIPAL CONTENTS

page

ECONOMICS OF SMALL NUCLEAR POWER UNITS *by* **J. M. Kay**
L'aspect économique des petits groupes d'energie nucléaire
Die Wirtschaftlichkeit kleiner Kernkraftwerk Einheiten
El aspecto económico de las pequeñas unidades de energía nuclear 225

RESEARCH FACILITIES AT THE G.E.C.-SIMON CARVES ATOMIC ENERGY DEPARTMENT
Les facilités de recherches à la Section d'Energie Atomique de la G.E.C.-Simon Carves
Forschungs Einrichtungen für Atomenergie in der Spezialabteilung der G.E.C.-Simon Carves
Facilidades para investigaciones en el Departamento de Energía Atómica G.E.C.-Simon Carves . 228

PROBLEMS OF MECHANICAL ANALYSIS IN REACTOR TECHNOLOGY *by* **G. Horvay**
Les problèmes de l'analyse mécanique dans la technologie des réacteurs
Probleme der analytischen Mechanik in der Reaktor Technologie
Problemas de análisis mecánico en la tecnología del reactor 231

THE WORLD'S REACTORS: NUMBER 5—ZEUS
Les Réacteurs dans le Monde: Numero 5—ZEUS
Reaktoren in der Welt: Zahl 5—ZEUS
Los Reactores del Mundo: Numero 5—ZEUS . . . . . facing 234

ACTIVITIES OF THE UNITED STATES ATOMIC ENERGY COMMISSION
Les travaux de la Commission d'Energie Atomique des Etats-Unis
Die Arbeiten der United States Atomic Energy Commission
Actividades de la Comisión de Energía Atómica de los E.E. U.U. de Norte América . . . 235

LIQUID METALS AS HEAT-TRANSFER MEDIA
Les métaux liquides en tant que moyens de transfert de chaleur
Flüssige Metalle als Medien für die Wärmeübertragung
Los metales líquidos como medios de transferencia de calor 238

FIRST COMMERCIAL PRESSURIZED-WATER REACTOR
Le premier réacteur commercial à eau pressurisée
Der erste gewerbliche Druckwasser Reaktor
El primer reactor comercial de agua presurizada 241

DESIGN ASPECTS OF RADIATION INSTRUMENTS *by* **E. N. Shaw**
Les aspects de la construction des instruments de radiation
Verschiedene Punkte für den Entwurf von Strahlungsinstrumenten
Aspectos del diseño de instrumentos de radiación 245

A VERSATILE VAN DE GRAAFF
Un Van de Graaff à plusieurs emplois
Ein vielseitiger Van de Graaff
Un Van de Graaff de usos múltiples 250

HIGH-VACUUM METALLURGY
Métallurgie au vide élevé
Metallurgie im hohen Vakuum
Metalurgía de vacío máximo 252

REGULAR FEATURES

EDITORIALS 221
COMMENTS ON THE NEWS . . 223
WORLD NEWS 255
ORBITS IN INDUSTRY . . . 257
COMPANY NEWS 258
PERSONAL 259
PROCESSES AND EQUIPMENT . 260
PATENTS REVIEWED . . . 262

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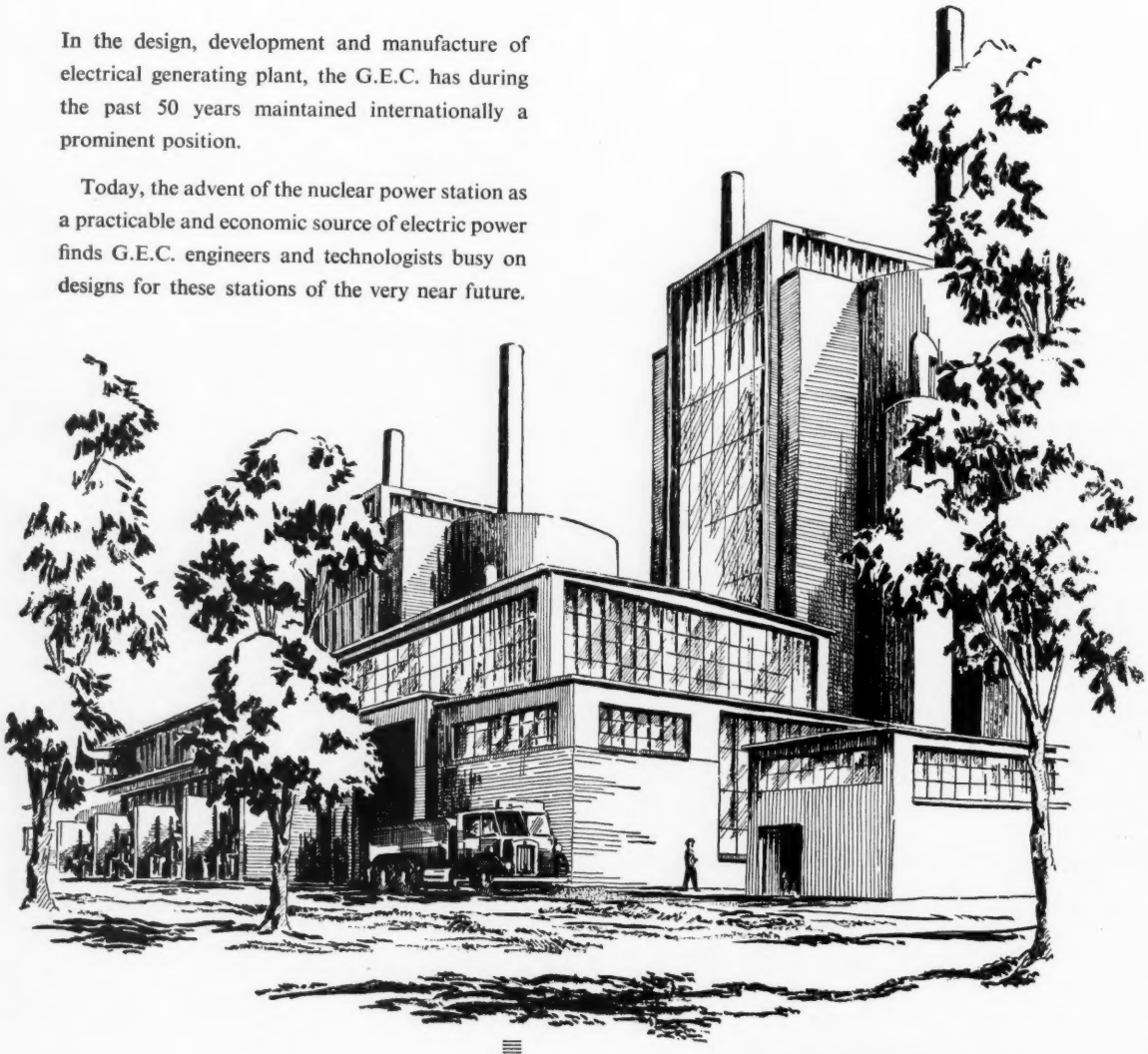

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NUCLEAR ENGINEERING VOL. I NO. 6 SEPTEMBER, 1956

EDITORIALS

Natural Uranium Reactor in U.S.A.

THE Bill which passed through the Senate calling for $400 million to be spent on an all-out power reactor development programme has been returned by Congress to the committee stage and will not be reconsidered before the adjournment. There is, therefore, a breathing space in which the controversial issues that have been raised can be reassessed and the rising emotions that the Bill has evoked can be replaced by a more objective approach.

The protagonists of the Bill claim that America is falling behind the rest of the world in the development of reactors for the production of power and that other countries, notably the United Kingdom and the U.S.S.R., are in a considerably more advanced position to produce electricity from atomic energy than the United States, whilst the opponents of the Bill claim that the work of the A.E.C. should be devoted to proving reactor types leaving the commercial exploitation of their conclusions to industry.

On both sides, however, the situation is obscured by arguments which make the *ad hoc* assumption that it is essential for the United States to lead in reactor developments. Presumably this is based upon prestige grounds which may have a purely altruistic and reputation background but which are more likely to be bound up with ultimate economic considerations. Alternatively, the explanation may lie solely in the political field where the reactions arise from fear of the consequences of a large proportion of the nations of the world being in a position to manufacture their own nuclear weapons. However undesirable this position may be it must ultimately be accepted that development policies should be based solely on the potentialities of the peaceful applications of atomic energy.

An accurate analysis of the relative positions of different countries in their reactor development programmes is obviously difficult because although many of the military-induced security restrictions have been lifted normal commercial reticence requires that a minimum of information should be disclosed on the advanced types of reactor system. There can be little question that even if the technology associated with some of these types in the U.S. is not advanced over other countries the experience gained over the past 11 years must play an important part in the construction and operation of generating stations once the optimum types have been decided. In naval ship propulsion, small transportable reactors, sodium-cooled reactors for example, accumulated knowledge in the U.S. must be greater than in any other country.

There are three main causes for the slightly hysterical view that has been taken of their own developments. The first is the shock and surprise engendered by Russian disclosures made at the Geneva Conference followed by statements on the probable reactor power programme of the Soviet Union. The second was the realization that the gas-cooled, natural uranium Calder Hall type, which even as late as Geneva was largely discounted as suitable for economic electricity production, is a sound proposition. Finally the indiscreet advertisements inserted by the utility companies in the major newspapers throughout the U.S. claiming an inate superiority in potential generating plant caused resentment amongst the general public and a strong wave of feeling that these companies could not be left solely responsible for such important developments.

Reactions to the Russian disclosures were largely political and are strongly associated with the military programmes of the two countries. The importance of this aspect we do not feel competent to discuss except to reiterate the point that the provision of adequate power facilities for a consumer industry is not essentially linked with military and weapon developments. The imminent operation of the first power station at Calder Hall has more serious consequences and exemplifies the danger of confusing obsolescence of design with obsolescence of type. Whilst there is little question that much of the Calder Hall design should be improved and designs included in the tenders to the C.E.A. will represent a considerable advance on the Calder Hall model these are essentially stages in the development of the same basic conception. At the Geneva Conference where these Calder Hall designs were discounted by many as being insignificant the chief mistake lay in assuming, therefore, that the type and basic conception on which they were built were unsound forgetting that these same designs were even then approaching three years old. The error has now been acknowledged and a belated attempt has been made to rectify the position by instituting a gas-cooled, graphite-moderated reactor development programme.

There is little question that the advertisements referred to above were unwise and that the reactions to them could have been anticipated but the utility companies are in the difficult position of being responsible for the production of power at an economic rate in a country where oil and coal are still plentiful, whilst at the same time feeling it necessary to keep abreast and even ahead of the developments in countries where the production of electricity is important *per se* and the cost of secondary importance. These countries, notably the United Kingdom, have shown almost incidentally that the production of economic power by a gas-cooled, graphite-moderated system is practicable and four companies will soon be in a position to undertake the construction of power stations to their own designs. Tenders which they submit will quote firm delivery dates and as firm operating costs as it is conceivable to give. The short cut, therefore, for the utility companies, who require to expand their production facilities within the next few years and who are desirous of maintaining a leading position in the world as electricity producers is to ask for tenders from the British companies for the construction of a gas-cooled, graphite-moderated natural uranium reactor power station to be built in the U.S. We are sure that this would be given active consideration.

The Necessity of Exports

WHILST provision for the expansion of the United Kingdom nuclear energy production facilities must remain of paramount importance to this country when considering her atomic energy programme the stage has now been reached when more attention can be devoted to export and to the types of plant that we should be ready and willing to produce.

The first types that are to be exported from the United Kingdom will be research or test reactors of various designs. The potential market for these reactors is difficult to assess as unfortunately questions of national prestige immediately arise. There is a strong feeling in almost every country that it is essential that an atomic energy section should be built up which must acquire experience on the construction and operation of reactors. It is usually of secondary importance that facilities would then be available for the production of short-lived radio-isotopes and of course for longer-lived isotopes although transport arrangements of these particularly from the United Kingdom are adequate to fulfil most requirements.

The major criteria in determining whether a research reactor should be bought or designed and constructed in the country concerned will be the quality of the indigenous technical staff and the urgency with which the programme is viewed. Clearly Western Germany has decided that urgency is of paramount importance and negotiations are in hand or complete for at least six reactors and possibly eight of various types but all falling into the research class. On the other hand India has successfully completed the construction of a swimming-pool reactor designed and built by her own personnel.

In terms of competition the supplying country will be chosen on cost, delivery times and conditions of sale. The United States Government is prepared to further the export of reactors by subsidizing up to 50% of the total cost and Canada has agreed to provide India, under the Colombo Plan, with an NRX type at, approximately, half the total cost. Subject to the provision that certain bilateral agreements have been made, which include the gift of small items of equipment for educational purposes, the United Kingdom does not propose to follow these precedents. Conditions of sale may favour the U.K. as British industry is inclined to be less tied up with political affairs than other potential exporters. This state of affairs must be encouraged and any tendency to link reactor sales with political conditions must be strongly resisted. This also applies to any cumbersome fuel reprocessing arrangements that may arise and it must be remembered that private ownership of fissile material is not barred in all countries overseas.

The export of power reactors for electricity production whilst being more of a straightforward commercial undertaking is still bound up with the importer's national prestige. It is possible that in a number of countries where from an economic point of view the special facilities for design and construction over and above normal industrial requirements should not be available, the special place which atomic energy has in national affairs may lead governments to divert a disproportionate effort and attempt projects themselves. In many cases, however, even where a long background of research reactor experience obtains, this will be devoted to continuing research in the use of nuclear radiations and in developing teams which are capable of operating a power reactor programme. Demand will fall into three main categories: large power reactors for base load work with outputs up to 300 MW, medium-sized power reactors with an installed capacity of 50 MW for the supply of relatively compact industrialized areas and the small generating stations of up to 15 MW installed capacity for supplying isolated communities, large chemical plants, etc., replacing or supplementing diesel generating equipment. At present the United Kingdom is in no position to seriously discuss the export of stations falling into these last two categories but it is in a singularly strong position for the supply of large reactor power stations based on the Calder Hall design.

Western Europe is an area where a considerable number of these stations will be built either by the resident nations or by countries able to export in the next 15 years. Outside Europe the outstanding potential customer is Japan which is sending a team of scientists to visit England in October to discuss the installation of a generating station of 100 MW or more installed capacity.

Whilst requests to tender for such a station could expect a warm welcome there is a minority feeling that a strong danger exists of a single unit being exported which then forms the pattern for other units to be constructed by the purchasing country. This is of course a permanent danger in the export of any goods and although British companies have at times had unhappy experiences the scale of the projects contemplated is of a different order, and even one contract to the value of £20 million is worth while. It is naïve to imagine that plans of any complex plant such as a nuclear power station could be copied and form the basis for developments in another country which could then (say five years later) compete on equal terms.

There are three types of knowledge involved in the construction of such a plant, the first concerns the basic design parameters which admittedly can be taken from a drawing almost in their entirety. The second concerns "know-how," a word that is very popular in recent years and presumably implies the abstract noun from the verb to "know" (how). If we define this as implying that a process is fully described and details of construction, tricks in the handling of the materials, etc., are included then "know-how" is clearly an important part of the manufacturing process but there is no necessity for much of it to be divulged.

The value of "know-how" however is frequently overrated in that although it is essential for this to be available for the process to be copied there is still a third more important factor which could be described as experience. This is inevitably a characteristic of the individuals working on the plant and is part of their make-up rather than any specific technique. There is no way of copying it and the only way of acquiring it is by passing through the same stages as the possessors of the experience or alternatively buying the possessors themselves, in which case a large measure of the know-how and the basic design parameters are also included in the deal.

There is thus a considerable danger in exporting personnel that the innermost commercial secrets will be available to competitors and we must ensure that the experience acquired by workers in this country is not neglected and that they cannot be induced to move to other countries to take up more attractive employment.

On the other hand exporting information can only lead to an increase in interest in British goods as a whole and with the essential feature of experience being absent represents no danger to future trade. Having achieved so much, the United Kingdom must be wary of turning insular in her dealings in the atomic energy field and work always on the assumption that invested in our innate ability and in our experience lie the essential characteristics that make for a continuously improving competitive product.

Comments on the News

NORTHERN IRELAND NUCLEAR POWER PROGRAMME

We regret the error that crept into last month's comment on the White Paper published by the Government of Northern Ireland, entitled "Electricity Supply in Northern Ireland", in which we pointed out that by 1969 approximately 4% of the total generating capacity will be represented by nuclear plant. This figure should, of course, have been 40%. Some criticism has been levelled at the decisions contained in the White Paper on the grounds that for the next six years only a stop-gap programme is planned, whereas a more intrepid approach would allow the installation of a nuclear power station by the end of 1960 to meet the expected deficiency arising at about that time.

Such criticism, however, fails to make due allowance for the essential differences between the generating requirements of Northern Ireland and of the United Kingdom. Obviously it is not anticipated that the first commercial power stations will be unreliable or intermittent in operation; but to plan a generation programme which allows for no teething troubles or modifications to practically untried plant imposes a rigidity of operation which few would feel justifiable. Furthermore, initial operation would, of necessity, be at a low load factor and therefore uneconomic. Rather than meriting criticism, the Electricity Board of Northern Ireland and its consultants are to be congratulated on a courageous and balanced appraisal of the significant factors.

INTERNATIONAL STANDARDS

The International Organization for Standardization at the annual council meeting in July held in Geneva agreed that it was urgent that national standards in the atomic energy field should be unified on an international basis both in the interests of export and in the free interchange of scientific and technical information. The council decided at Geneva that its technical committees should consider the fields of (1) terminology, definitions and symbols, (2) safety standards for protection against hazards from nuclear radiation, and (3) standards for the safe and effective operation of reactors. Close co-operation will be kept with the International Electro-Technical Commission, which has formulated its own plans in the electrical field. The I.S.O. council is elected by 37 national standard bodies including Belgium, Finland, France, Germany, Italy, India, Portugal, Russia, Spain, the United States, whilst the United Kingdom is represented by the British Standards Institution.

This Institution has recently circulated a draft glossary of terms used in nuclear science so that comments may be received and amendments made according to general opinion. The draft has been widely circulated amongst other standards bodies, the technical press, scientific institutions, industry, etc., so that a broad cross-section of opinion can be obtained. The glossary has been drawn up by a committee under the chairmanship of Professor O. R. Frisch composed of such representative bodies as the C.E.A., the U.K.A.E.A., the Atomic Scientists Association, the N.P.L. and SIMA. The committee has drawn freely on the proposed American standard entitled "A Glossary of Terms in Nuclear Science and Technology" and due acknowledgment is made to this work. The document is unavoidably lengthy and involves precise definitions of nearly 1,000 terms. At present the draft glossary is not complete but the committee decided that unnecessary delay in the collection of comments would be involved if completion was awaited.

REACTOR BUILDING CAPACITY IN THE U.K.

Doubts have been expressed that even if a large export trade should develop as a result of the Calder Hall and C.E.A. designs, the total capacity of British industry would not be sufficient to meet demands over and above those required for internal expansion. However, in a statement recently, a director of G.E.C. asserted that the limiting factor would not be the reactor side but the generating capacity of the country, which, by 1970, had been estimated at 5,000 MW per year, and that this figure could be achieved before that date if sufficient urgency arose. The present United Kingdom power programme nominally calls for the building of 12 nuclear power stations with an installed capacity of 200 MW each, but reliable estimates have placed this figure as pessimistic by at least a factor of three. For the purpose of argument therefore, it could be assumed that by 1965 the internal consumption in ten years will have amounted to a maximum of 10,000 MW, and that the following five years should not see a very considerable increase on this rate. Conventional plant calls for the installation of 9,000 MW in the five-year period up to 1960 and if this rate were to continue at, say, 2,000 MW per year, the overall requirements would still amount to only 3,000 MW per year. There is thus a considerable capacity in excess of this figure available for export and, taken in conjunction with the statement that a single company would be capable of having six reactors under course of construction at any one time, indicates that the limiting factor will almost certainly be available market rather than available capacity.

DEVELOPMENT RESPONSIBILITIES

Paragraph 141 of the A.E.A.'s annual report allows for a generous amount of interpretation. It states that the Authority has decided that research into, and development of, nuclear reactors for future military application should be part of the responsibility of the weapons group under the direction of Sir William Penny. This arrangement will not affect the submarine reactor under development by the Admiralty. The important question this poses is which reactors constitute military application. Clearly, for a long time to come any aircraft developments involving nuclear propulsion units will be a military undertaking rather than a civil enterprise, and it is expected that propulsion units for ships will be largely devoted to the requirements of the Royal Navy until such time as international agreements have been worked out on the safety factors relating to merchant vessel application. Also, civilian projects must wait until power units of this type can compete from an economic point of view with oil-fuel units, bearing in mind that oil for ship propulsion is the cheapest available. In the United States the major development in small semi-transportable power units has been undertaken for military applications (viz, the APPR). Are we to infer, therefore, that also included in the weapons programme in the United Kingdom is the design and development of such reactors?

Power units of this size are liable to represent a major part of our nuclear export trade in the future—the time scale varying from an optimistic five years to 15 or 20 years. It is desirable that, because of this export trade, industry should be familiar with all developments in the small reactor field so that, when the time is ripe, adequate production experience is available. Linking such developments with the weapons programme would certainly impose security restrictions which

would at the very least hamper a widespread interest in the experimental results and could only lead to a slowing down of the peaceful applications. Similarly, a number of companies are looking ahead to the time when gas turbines will be applicable in this field and developments will almost certainly impinge on the weapons projects, with again a clamping down of security restrictions. It has always been a fear that plutonium-fuelled reactors would be sufficiently close to atomic-bomb projects that release of information would be slow. Full justification for these fears is shown by the influence exerted on thermo-nuclear development declassification, which has been prevented largely by the American and British bomb programmes. We must be careful that the implied change of emphasis in the report is aimed at widening the scope of the establishments previously devoted to weapons work to bring their interests out of the strictly militaristic field, and that a return to the immediate post-war days of extensive security restrictions with information always "born classified" does not materialize.

One can sympathize with the heads of establishments such as A.W.R.E. in their recruitment campaign that, in general, technical staffs are not prepared to devote their life's work solely to the production of atomic and thermo-nuclear bombs. Top-line experimentalists in the atomic energy field are noted for their reluctance to concentrate entirely on weapons research, and if the quality of this work is not to suffer additional incentives must be introduced to attract the right type of personnel. The chief danger lies in the influence of executives brought up in armament establishments being extended to cover work that is essentially of peaceful import and on general principles holding back information that should be disseminated amongst the industry.

IN-PILE FACILITIES

As power-reactor developments progress leading to systems operating at higher temperatures and higher flux densities, the need for materials-testing reactors with large in-pile facilities capable of taking hot-loop experiments for protracted periods of time becomes more urgent. At present in this country we have no high flux reactor operating, capable of taking such loops, although DIDO is expected to become critical this month. PLUTO should be available towards the end of next year, and a second version of this is being built at Dounreay. The total facilities, however, that these reactors offer will only barely cater for the needs of the U.K.A.E.A. itself, and although industry will be able to co-operate in many of the experiments being undertaken, further provision must be made if a general hold-up to the programme is not to arise. The eight reactors at Calder Hall and Chapel Cross can be used for certain in-pile experiments on fuel elements, but no provision has been made for the undertaking of hot-loop investigations. Both industry and the A.E.A. are aware of the limitations imposed by the present facilities, but for economic reasons it has been decided that future materials-testing reactors should be dual-purpose plants designed to provide information on new reactor designs as well as in-pile facilities for research. It is improbable, therefore, that big high flux reactors will be built by industry for their own use except as part of a general feasibility programme. The smaller reactors, such as Merlin, although offering facilities for small low-temperature experiments and for training of personnel in the type of nuclear plant met with in power stations, cannot provide facilities for the high-temperature and high-pressure work that will be required in the future. It is important, therefore, not only from the reactor design development programme alone but also from the additional facilities that will result, that decisions are taken in the near future on the type of reactor that is to be singled out for stage-two development.

"Nuclear Engineering" Directory, 1957

A directory of the nuclear engineering industry compiled by the staff of *Nuclear Engineering*, will be published by Temple Press Ltd. in 1957 under the title of *"Nuclear Engineering" Directory, 1957*. The object of the directory is to provide a complete reference guide to this important British industry and its many branches in allied spheres of engineering. The directory will include detailed lists of all British suppliers of equipment, components and material for use in the nuclear engineering field, classified under more than 400 product headings and with index aids to rapid reference. It is planned to make *"Nuclear Engineering" Directory* fully representative of the industry to form a valuable source of reference for potential customers at home and abroad.

Other British industrial directories published by Temple Press Ltd. include *The Aeroplane Directory of British Aviation, Farm Mechanization Directory, The British Diesel Engine Catalogue* and *The British Commercial Vehicle Industry*.

NUCLEAR ENGINEERING SCHOLARSHIP

The annual scholarship for research into engineering problems relevant to atomic-energy developments offered by *Nuclear Engineering* has been awarded for the year 1956-7 to Mr. A. F. Pexton. The scholarship is valued at £400 for the twelve months. Mr. Pexton is to begin a course of study into boiling phenomena in liquids and their effect upon heat transfer. This is a continuation of some work started at Harwell and will be directed towards the determination of the relative velocities of boiling water and the entrained vapour bubbles moving along a pipe. From the results it is expected that heat transfer coefficients of boiling water can be derived. The study will be undertaken at Manchester University. Mr. Pexton completed the first course in Mechanical Sciences Tripos at Cambridge in 1955 with honours and has spent one year's post-graduate apprenticeship with the de Havilland Engine Co. Ltd.

DEPRECIATION IN THE U.K.A.E.A.

Appendix three in the second annual report of the United Kingdom Atomic Energy Authority, paragraph eight, contains an interesting statement of the figures used for calculating amortization. A correct interpretation of these figures should yield a clear insight into the nature of the building projects undertaken and also to the characters of the inhabitants. Probably the most significant number is the 10% per year quoted for the reactor and chemical process plant and equipment which should be compared with the 15-year life quoted by Jukes in his paper at the Geneva Conference. One must infer probably that the treasury requirements for accounts are not the same as commercial requirements, and that this difference of five years does not represent a sudden change of faith in the real life of the reactors referred to. Alternatively, of course, the ten-year period may refer only to research reactors and not power reactors, the period being judged on the useful life from the application's point of view and not from the genuine life of the structure.

It is perhaps a solemn commentary on modern life and our predeliction for prefabricated work that permanent buildings will only last twice as long as temporary buildings. Finally, the costing associated with furniture and fittings conjures up a picture of sober and studious scientists working away in their laboratories and in their offices with due dignity and decorum, returning to their hostels to begin a night life and week-end life of gay abandon inevitably resulting in a marked increase in depreciation of the surrounding objects.

The Economics of Small Nuclear Power Units

by

J. M. KAY, M.A., Ph.D., A.M.I.Mech.E.

A large-scale power programme will probably be based on a mixture of reactor types using natural and enriched uranium. There is evidence to suggest that a small reactor power plant may soon be competitive with Diesel units where fuel costs are high.

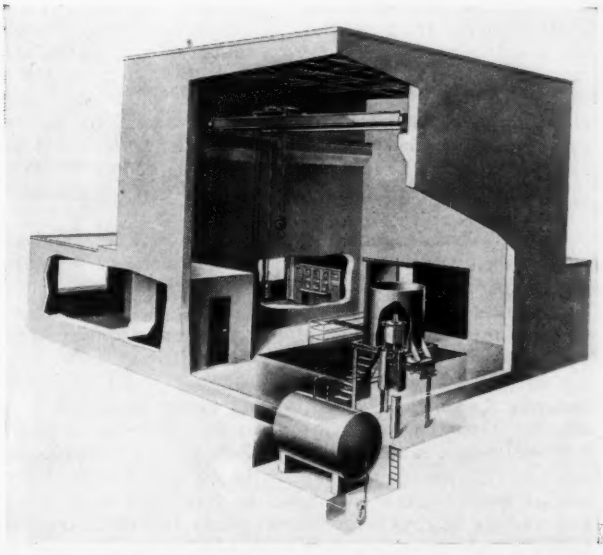
THE main effort in the nuclear-power field at the present time is directed towards the design, development and construction of nuclear reactors of large size. In the United Kingdom in particular the main emphasis is on the graphite-moderated, gas-cooled reactor which is likely to become most attractive as an economic proposition when designed for an electrical output of not less than 100 MW.

There are several reasons for this concentration of effort on power plants of large capacity. In the first place it is generally necessary to make a start with natural uranium as the fuel in the opening phase of any large-scale power programme. There are only two basic types of natural uranium reactor which can satisfy the demands of engineering feasibility, and both these reactors are of relatively large physical dimensions and must consequently be developed to large individual power outputs if they are to compete economically with conventional power plants. The graphite-moderated, gas-cooled reactor is rapidly establishing itself as the classical system for using natural uranium fuel, and the economics of this type of plant have been outlined in a previous article (*Nuclear Engineering*, Vol. 1, No. 2, May, 1956).

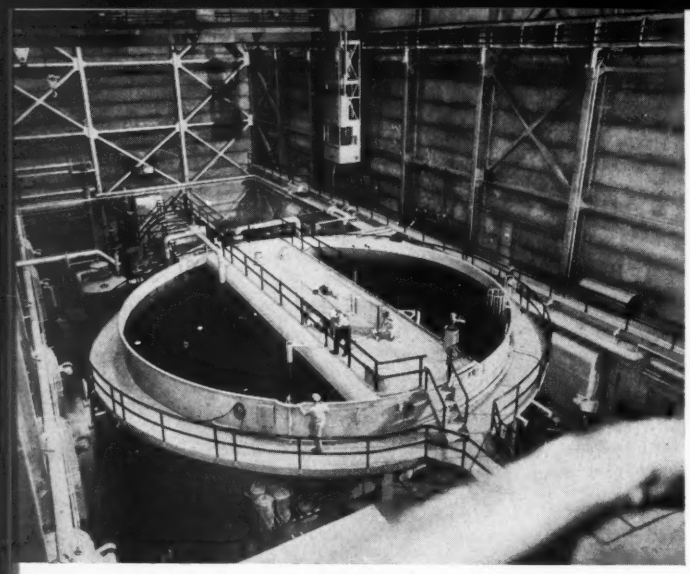
Another reason for the present emphasis on large sizes of plant is the fact that nuclear power must generally involve higher capital costs than those normally associated with conventional power stations. The fuel costs, on the other hand, may be lower for the nuclear plant, provided that certain conditions are satisfied in the design. It follows from this that the first and most obvious field of application is for power generation at high load factor in large base-load generating stations. The natural range of size for individual turbo-alternators in base-load power stations at present under construction in this country is from 100 to 200 MW. It so happens that this is just about the range of electrical output for which a graphite-moderated, gas-cooled reactor can be designed at the present time, using existing materials and known techniques. The future tendency will undoubtedly be towards still larger sizes, both from the point of view of the size of generating unit actually required by the electricity system and also because the engineering development of the graphite-moderated reactor will enable the power output of later designs to be increased, thus reducing the capital cost per kilowatt.

In a few years' time the distinction between natural uranium fuel and slightly enriched uranium may be of less importance than it is at present. When the first phase of a large-scale nuclear power programme has been completed and a number of natural-uranium-fuelled reactors are in operation, a regular supply of by-product plutonium will begin to become available for use in providing enrichment for other reactors. In addition to this, it may also be possible to justify economically the use of enriched uranium from diffusion plants to a limited extent. In general, however, it would be necessary for a diffusion plant to be located in an area where power is available at very low cost. It is thus probable that in the second phase of any large-scale nuclear power programme there will be a complex system which will include natural uranium reactors, reactors using slightly enriched fuel, and the necessary supporting chemical and diffusion plants. Recycling of material will take place in various ways within this system, and it is consequently rather difficult to consider the economics of enriched uranium reactors in isolation and without reference to the system in which they are designed to operate. This point has already arisen by implication in the preceding article on the economics of enriched-fuel reactors (*Nuclear Engineering*, Vol. 1, No. 4, July, 1956).

When the stage has been reached that there is a fair quantity of enriched fuel in circulation as a result of the building-up of the main base-load power station system, the diversion of a certain amount of enriched material to provide fuel charges for smaller reactors may become commercially feasible. The main purpose of this concluding article is to review the possibilities for small or medium-power nuclear reactors in the range of 5 to 30 MW electrical output. Many statements have been made about the benefits that nuclear energy will confer on underdeveloped countries and in providing power in isolated areas, but unfortunately these



An impression of the APPR built for the U.S.A.E.C. by Alco Products, Inc., with additional pressure containment for experimental purposes.



Overall view of the sea tank in which a replica of the *Nautilus* hull containing the nuclear propulsion unit ran under test for a continuous period of 66 days.

statements have tended to be over-optimistic. It has to be remembered that a power plant that is intended to supply electricity in some isolated area must be extremely simple both in operation and in maintenance, and it must also achieve a very high degree of reliability. This is really a much more serious problem in the case of the small reactor than it is for the large base-load reactor operating as part of an interconnected system with sufficient stand-by plant always available. It also has to be remembered that in the small or medium-power field nuclear reactors will be competing with Diesel generating sets, the designs of which are based on many years of development and operating experience. In spite of these reservations, however, it can only be a matter of time before medium-power nuclear reactors establish themselves provided that there is a reasonable prospect of ultimately achieving costs that are competitive with Diesel or oil-fired plants.

While it is known that a number of small experimental reactors have been built and operated successfully, it is also known that these have generally involved the use of a fairly high degree of enrichment and no particular attempt has been made to aim at the production of economic power. One of the few detailed studies of the economics of a small nuclear reactor is that of the experimental boiling water reactor plant of the Argonne National Laboratory, which has been described in a paper by Harrer, Jameson, and West in the *Proceedings of Geneva Conference*. It is worth while to summarize some of the figures published in connection with this particular scheme before attempting to make any general forecast.

The EBWR is designed for a heat rating of 20 MW and an electrical output of 4.5 MW. The dimensions of the core are approximately 4 ft. diameter by 4 ft. length. Two sets of fuel elements are employed, one containing natural uranium and the other U 235 diluted with zirconium. Steam generated in the core of the reactor is supplied direct to a steam turbine without any intermediate heat exchanger. This is probably basically the simplest type of nuclear power plant that it is possible to conceive. Whether the use of steam direct from the reactor is a practicable proposition from a maintenance point of view, however, remains to be proved. An essentially similar reactor could, of course, be built incorporating an intermediate heat exchanger so as to keep the reactor coolant circuit self-contained, but there would be some penalty to pay in the slightly higher cost of the plant and inferior steam conditions. The estimated cost of the EBWR reactor, including the cost of fabricating the core but not of providing the fuel, amounts to $4,000,000. This works out at slightly over £300 per kW of electrical output. The calculation of the fuel replacement cost is complicated by the fact that there are the two different types of fuel element to be considered with their relative rates of burn-up and replacement. The estimated cost of power, however, translated from the paper quoted above, may be summarized in the following table for a load factor of 80%:

EBWR: estimated cost of electrical power generated at 80% load factor

	Pence per kWh
Capital charges (including fuel rental) ...	1.72
Fuel replacement	0.49
Operating costs	0.72
Total in pence per kWh	2.93

A development of the EBWR is also considered in the paper quoted above to give a heat rating of 40 MW and an electrical output of 9 MW. It is estimated that this could be achieved for an additional cost of $800,000, i.e. the total plant cost would be $4,800,000 which corresponds to £190 per kW of electrical output. The cost of power generated at 80% load factor would then be as follows:

EBWR at 9 MW electrical output

	Pence per kWh
Capital charges	1.02
Fuel replacement	0.49
Operating costs	0.36
Total in pence per kWh	1.87

Both these estimates might be open to criticism for taking optimistic fuel costs, since they are based on an irradiation of 10,000 MWD per ton and on the quoted American figure for the cost of U 235. On the other hand, the capital charges may be pessimistic, not so much in regard to the actual capital cost per kW of the plant as in the annual charges which would apply to this capital outlay. Also the operating cost would seem to be rather high.

Another estimate is available for a 10-MW pressurized-water reactor based on the U.S. Army package power reactor

L'aspect économique des petits groupes d'energie nucléaire

Alors qu'au stade actuel les progrès dans le domaine de l'énergie se concentrent sur les réacteurs qui se servent de l'uranium naturel comme combustible, le temps viendra où la distinction entre l'uranium naturel et l'uranium au moins légèrement enrichi sera peut-être de moindre importance. Cela se produira par suite du fait que le plutonium deviendra disponible, et du fait que des approvisionnements en U 235 produit dans des installations de diffusion employant de l'électricité à un prix abordable seront détournés des fins militaires. Les programmes d'énergie seront alors basés sur un système complexe de réacteurs employant de l'uranium naturel et enrichi.

Les possibilités immédiates de l'application de l'énergie atomique aux petits groupes électrogènes ont fait l'objet d'exagérations, vu qu'outre les dépenses, il faut que le fonctionnement et l'entretien puissent être assurés par du personnel non expérimenté. Toutefois, en prenant comme base de calcul l'expérience EBWR de l'Argonne où le rendement en chaleur de 20 MW était alimenté directement sous forme de vapeur dans les turbines, une dépense de capitaux de 4 millions de dollars pourra entrer en ligne de compte, et donnera un prix de revient de production de 2,93 pence/kWh. Si, tel qu'indiqué, le régime pourra être doublé avec une dépense supplémentaire de 800.000 dollars, cette fois-encore pour un facteur de charge de 80%, on obtiendra un prix de revient de 1,87 pence/kWh. Des calculs optimistes basés sur l'APPR réduisent ce chiffre à 1,44 pence/kWh.

Toutefois, il ne devrait pas être impossible dans un proche avenir, même avec le facteur de charge plus probable de 40% d'obtenir la production de 5 MW à 2,92 pence/kWh et de 10 MW à 2,23 pence/kWh, ce qui serait à même dans certains cas de faire concurrence à la production d'énergie par les moteurs diesel.

(*Nuclear Engineering*, Vol. 1, No. 4, July, 1956). The figures may be translated as follows:

10-MW pressurized-water reactor at 80% load factor

	Pence per kWh
Capital charges	0.50
Fuel replacement	0.81
Operating costs	0.13
Total in pence per kWh	1.44

If we now attempt to generalize the position for reactors of either the boiling-water or pressurized-water type in the range of 5 to 10 MW electrical output, it would not be unreasonable to assume plant costs ranging from £300 per kW at one end of the scale to £200 per kW at the higher power output. The plant cost would thus be £1,500,000 for a 5-MW reactor and £2,000,000 for a 10-MW reactor. Taking an effective life of twenty years and an interest rate of 5%, the annual capital charges would be £120,000 and £160,000 respectively. The cost of the fuel might be in the neighbourhood of £500,000 and the rental at 4% would therefore involve a further annual charge of £20,000. For the fuel-replacement cost it would be wise to take a figure rather higher than the estimates for the EBWR reactor, implying that the cost of fissile material would be greater than the quoted American figure and that we would not be counting on achieving a very high level of irradiation. The following might therefore be a reasonable estimate for the 5 to 10 MW range operating at 80% load factor:

	5 MW	10 MW
Capital charges	0.96	0.62
Fuel replacement	0.85	0.85
Operating costs	0.15	0.15
Total in pence per kWh ...	1.96	1.62

The figure of 80% for the load factor, assumed in all the above estimates, is high for a power plant in an isolated area. Assuming instead a 40% load factor, the corresponding figures for the total cost of power in pence per kWh would be 2.92 and 2.23 for the 5-MW and 10-MW cases respectively. Costs of generation for a range of load factor are plotted in Fig. 1.

There are many instances of Diesel generating stations operating with power costs in the range from 1.5 to 2.0 pence per kWh sent out. It would therefore seem that, with systems for which a load factor of not less than 50% can be achieved, there may well be a case in a few years' time for the small nuclear reactor of 5 to 10 MW electrical output. There will certainly be a case for nuclear reactors in the medium-power range, say from 15 to 30 MW electrical output, in some overseas territories.

A very large proportion of the total world consumption of conventional fuels is used not for the generation of electricity but for the production of heat. Some of this heat is required for industrial processes involving high temperatures as in the metallurgical industries, and there is unfortunately no prospect yet of nuclear energy being applicable in this field. A large part of the industrial heating demand, however, is for low-grade heat and in particular for process steam. It is quite possible that nuclear reactors of moderate size may be used for this purpose in countries where conventional fuel costs are high, and it is interesting to note that schemes have already been put forward in Norway and Sweden for industrial steam-producing reactors.

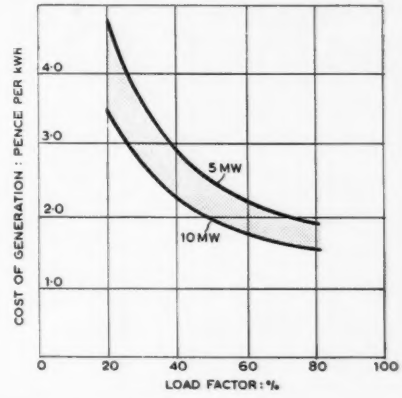


Fig. 1. Generating costs of a small reactor power unit expressed as a function of the load factor. Prices are likely to be competitive at load factors exceeding 50%.

Die Wirtschaftlichkeit kleiner Kernkraftwerk Einheiten

Während zur Zeit die Entwicklung auf dem Felde der Krafterzeugung sich auf Reaktoren konzentrieren wird, die mit natürlichem Uranium als Betriebsstoff arbeiten, ist die Zeit vorauszusehen, wenn die Unterscheidung zwischen natürlichen und zum wenigsten leicht angereichertem Uranium von geringerer Bedeutung sein wird. Dies wird dann eintreten, wenn Plutonium verfügbar sein wird, ferner wenn U 235 zur allgemeinen Verwendung kommen kann, das in Diffusions Anlagen produziert ist, welche billige Elektrizität benutzen, die für militärische Zwecke nicht mehr nötig ist. Programme für die Krafterzeugung werden dann auf der Grundlage eines komplexen Systems von Reaktoren aufgestellt werden, bei denen natürliches und angereichertes Uranium verwendet wird.

Die Möglichkeiten der sofortigen Anwendung der Atomenergie für kleine Kraftwerke ist übertrieben worden, da, abgesehen von den Kosten, Betrieb und Wartung durch ungelerntes Personal möglich sein müssen. Immerhin kann man, wenn man als Grundlage für eine Berechnung der Kosten das Experiment der EBWR in Argonne in Betracht zieht, wo die erzeugte Wärme von 20 MW direkt als Dampf zu den Turbinen geleitet wurde, als notwendiges Kapital eine Summe von $4.000.000 annehmen, was dann umgerechnet 2,93 pence/kWh Erzeugungskosten ausmachen würde. Wenn, wie angedeutet, die Leistung durch eine weitere Anlage von $800.000 verdoppelt werden könnte, dann würden bei Annahme eines Belastungsfaktors von 80% die Kosten auf 1,87 pence/kWh heruntergehen. Optimistische Schätzungen auf Grundlage der APPR bringen diese Zahl noch weiter herunter auf 1,44 pence/kWh.

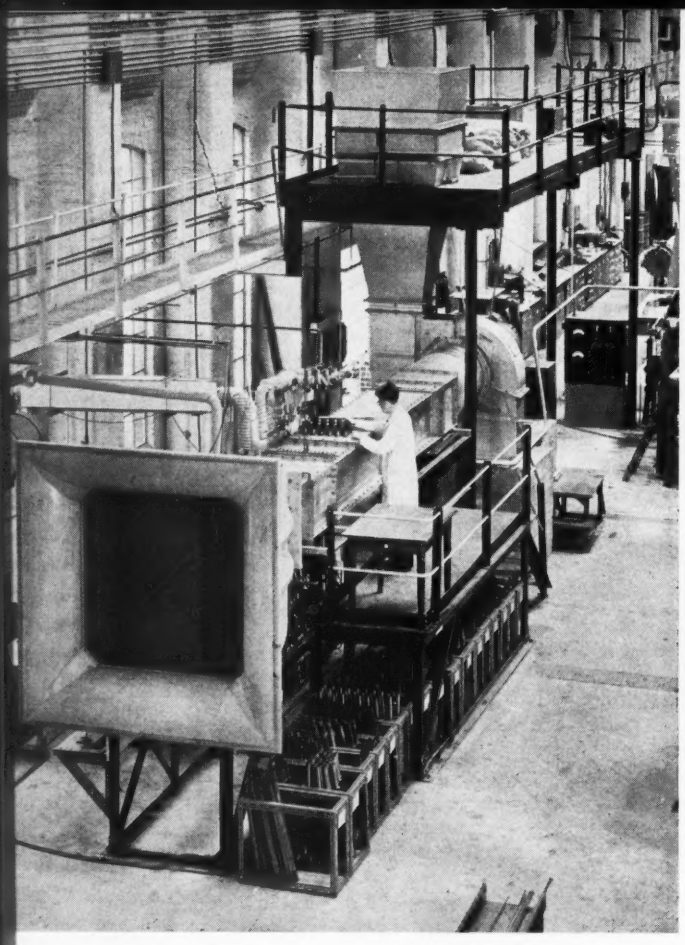
Es sollte indessen nicht unmöglich sein sogar in nicht zu weiter Zukunft bei einem mehr wahrscheinlichen Belastungsfaktor von 40% eine Krafterzeugung von 5 MW für 2,92 pence/kWh und 10 MW für 2,23 pence/kWh zu erzielen, was dann in manchen Fällen die Möglichkeit geben würde mit der Krafterzeugung durch Dieselmotoren zu konkurrieren.

El aspecto Económico de las Pequeñas Unidades de Energía Nuclear

Mientras que en la etapa actual los progresos en el campo de energía serán concentrados en los reactores alimentados por uranio natural, llegará el tiempo cuando la diferencia entre el uranio natural y por lo menos el uranio un tanto enriquecido podrá ser de menos importancia. Esto llegará a tener lugar mediante la disponibilidad del plutonio y encauzando los abastecimientos de U 235 producidos en instalaciones de difusión empleando electricidad barata a fines no militares.

Las posibilidades inmediatas de la aplicación de energía atómica a las pequeñas centrales generadoras han sido exageradas, ya que, prescindiendo del costo, la operación y el mantenimiento deberán ser posibles con el empleo de personal impericial. No obstante, tomando como base para cálculos, el experimento EBWR en el Argonne donde el rendimiento de calor de 20 MW fué alimentado directamente como vapor dentro de las turbinas, se puede considerar un gasto capital de 4 millones de dólares que da un costo de generación de 2,93 peniques por kWh. Si, como se indica, el regimen puede ser doblado por un gasto adicional de $800.000, nuevamente a un factor de carga del 80%, se llega a un costo de 1,87 peniques por kWh. Los cálculos optimistas basados en el APPR hacen bajar la cifra a 1,44 peniques por kWh.

Con todo, no debe resultar imposible en el futuro cercano, aun con el factor de carga más probable del 40%, alcanzar una generación de 5 MW a 2,92 peniques por kWh y 10 MW a 2,23 peniques por kWh, lo que, en algunos casos, puede llegar a competir con la generación por diesel.



Experimental facilities for the measurement of heat transfer characteristics. Samples of heat exchanger tubes tested are stowed in bins in centre foreground.

Nuclear Researc Fac

at G.E.C.-Simon Carv Ato

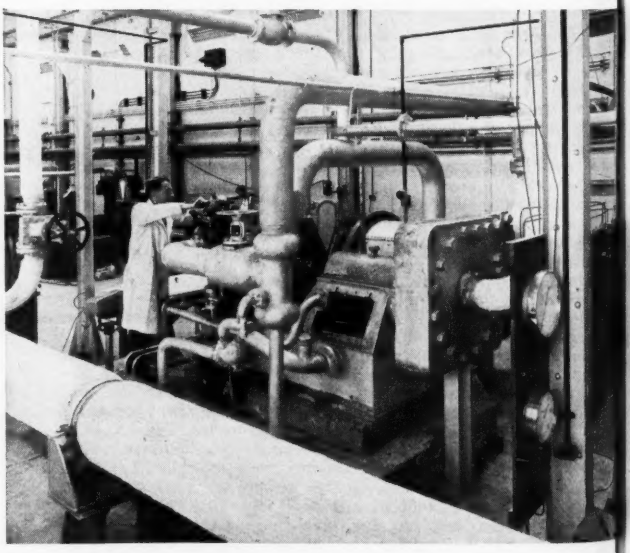
FOR some time prior to the announcement of the Government scheme for the building of a large number of reactor power stations by industry, G.E.C. had been making plans for the setting up of its own research and development department. The White Paper, however, lent an unusual urgency to these preparations, as from the date of publication a bare twelve months was allowed for the presentation of designs containing details of the major parameters, with a further six months only for the submission of the complete tenders. During the two years in which the Company have been actively engaged on building up their design team, now composed of over three hundred people, a considerable amount of research has been performed on various problems associated with the application of atomic energy to electricity generation. Costs have been large and a conservative estimate put running expenses of the department at £500,000 per year.

At an early stage it was appreciated that the major problems involved were those concerned with heavy engineering and with the metallurgy of construction materials. A further important aspect of research was in the heat-transfer field to determine the optimum conditions for conducting the heat from the uranium to the sheath, from the sheath to the carbon-dioxide coolant and from the coolant to water for raising steam. The constitution of the staff is loaded heavily on the side of the engineers, who require about 7% physicists and 25% metallurgists to support them. The technical Press has recently been shown some of the test rigs and laboratories situated at Fraser and Chalmers in Erith, where the design effort of the department is now concentrated. Details of the tender to be submitted to the C.E.A. by October will, of course, not be made public until after the placing of the first contract.

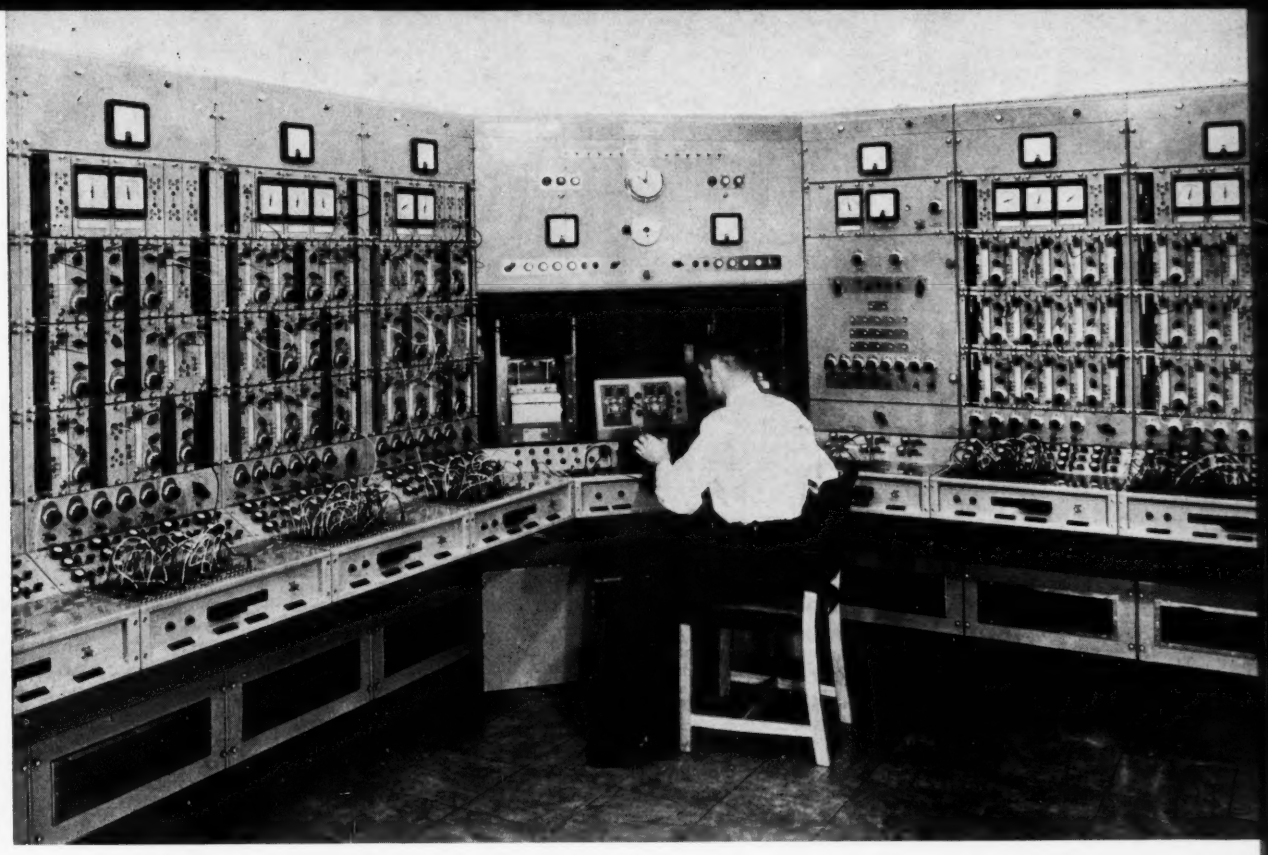
On the metallurgical side, compatability tests have required the extension of research performed by the U.K.A.E.A. to cater for the higher temperatures and pressures likely to be encountered in the first nuclear power stations as compared to the Calder Hall design. In a battery of 23 autoclaves compatability tests on many constructional materials have been made with pure carbon dioxide and CO_2 contaminated with the expected concentration of carbon monoxide and water. Eight types of steel have been under test to determine the optimum materials for the bulk constructional materials. A number of fuel element alloys have been investigated, including aluminium, magnesium, zinc, beryllium and niobium at 200 p.s.i. CO_2 and at temperatures from 300 to 500°C. This work has shown that the differences reported at the meeting of the Institute of Metals in April when metallurgists from Harwell indicated that aluminium was a preferred canning material, whilst Culcheth preferred magnesium, was due to the experimental conditions, notably the pressure of the carbon dioxide, and that at the pressures to be used a magnesium alloy (including Al, Ca, Be) similar to "magnox" is satisfactory at temperatures up to nearly 500°C.

This trouble, however, with oxidation will not be the critical feature when determining optimum fuel element material, and the more important criterion will be concerned with creep. Creep of the fins of a number of fuel element can structures made of various materials has been measured and additional work on creep and stress corrosion of constructional materials has been performed in a large furnace capable of taking the complete test rig including the direct loading. Dimensional changes are observed through a viewing port in the furnace.

A number of test rigs of various sizes have been set up to determine the friction factor and Stanton number of a series of extended surface designs. A close-fitting, stainless steel tube is inserted into the hollow member and thermocouple



Test rig for the measurement of heat transfer properties of fuel elemen a stream of carbon dioxide at 200 p.s.i. Various types of element ca accommodated and their characteristics determined by taking thermo-co readings and power consumption of the centrally fitted stainless-steel he element.



General view of the power station simulator installed in a pressurized room for the determination of response of the whole reactor generator system to transients. One cabinet is permanently wired for the reactor kinetics equation whilst six additional cabinets, each identical, allow a wide range of computing problems to be solved.

Facilities

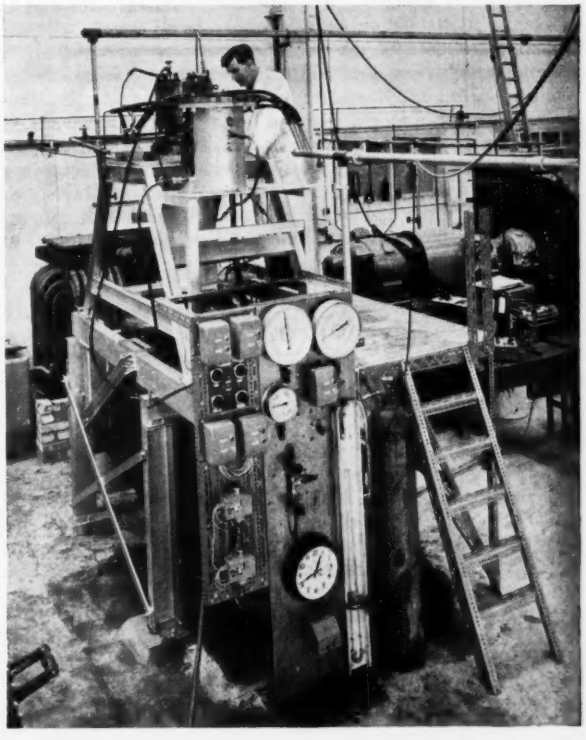
Atomic Energy Department

readings are taken of the can surface and gas temperature for various conditions of flow around the outside. This measurement, together with a knowledge of the power absorbed from the stainless steel tube heated by passing a current through it, gives the required parameters. Such measurements have been made in air and carbon dioxide at pressures up to 200 p.s.i. and have given valuable information on the heat exchange characteristics of the fuel elements and heat exchanger tubes.

Reactor designs call for a number of moving parts to be installed either within the pressure shell itself or at points within the biological shield quite inaccessible during normal procedure, and lubrication of these parts presents, therefore, a serious problem. Test rigs designed to check the efficiency of various bearing surfaces and lubricants in the presence of hot carbon dioxide under pressure are giving information on this subject.

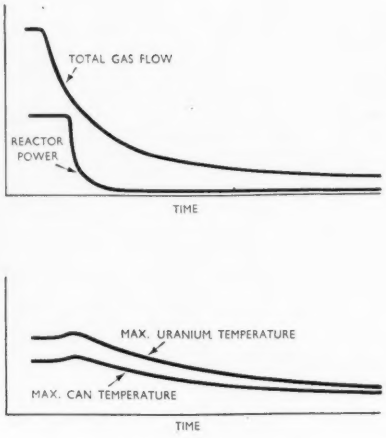
Oil seals in the cooler circuits are a further mechanical design problem, and a new seal just completing tests consists of a hub with a right- and left-hand helix turned on the surface extending from approximately $\frac{1}{2}$ in. from each end to within $\frac{1}{8}$ in. of the central circumference. This hub, running in a close-fitting housing and fed with oil from near the two ends with an outlet at the centre and driven at high speed, forms an effective barrier between bearing parts and the carbon-dioxide circuits.

To simulate accurately the problems that will be incurred in control rod drive, a test rig has been installed so that detailed measurements can be made of speed of operation,



High-pressure test rig used in the development of gas seals to isolate the CO_2 system from bearing lubricants.

General view of the metallurgical testing laboratories. Furnaces are used for making compatibility tests and creep tests on materials.



Typical recorder curves showing response of the system to a sudden failure of all the circulators.

velocity-damping, inching, etc. Present-day philosophy of panic shut-downs, however, does not require quite the rapid movement of control rods once envisaged, and protection of the system against mechanical jars is therefore eased.

Sealing of the fuel-element cans, both top and bottom, can now be performed automatically. Into the end of the can is placed a "U"-shaped pressing of the alloy with a tube through the centre for pumping and supported from the uranium by a special mechanical spacer. The can and end pieces are then sealed automatically by argon-arc welding. The can is mounted in a chuck which is caused to rotate at a predetermined speed once the arc has been struck and allowed the initial section to heat up to the required temperature. Although this operation is likely to be performed by the Atomic Energy Authority, the company has seen fit to devise its own methods suitable for its own can design.

Contamination of the coolant gas presents a number of metallurgical problems apart from neutron absorption problems, in that a speck of foreign metal in the coolant gas may adhere to the fuel-element can with which a eutectic rapidly forms at 300°C and very rapidly at 500°C, resulting in the early appearance of pin holes and necessitating the removal of the element long before the available MWD/ton have been achieved. An anodizing process has been developed in which the fuel-element can is placed in a fluoride bath with a high chromium content and A.C. is passed between the can and a second electrode. On removing and cleaning, the can is immune to metallic contaminants at temperatures up to 550°C.

Reactor Simulator

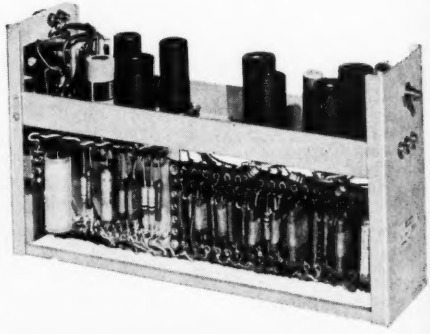
An important part of the design work concerns the determination of the various reactor parameters under unsteady state conditions such as start-up, blower motor failure, etc.

To determine the response of the nuclear power station to transient effects, a reactor simulator constructed by Elliot Bros., of Boreham Wood, has been installed in a special room in the laboratories. The room is maintained at a pressure slightly above atmospheric to minimize the ingress of dust. The simulator is an analogue computer with six identical cabinets and a special computer designed to simulate the reactor kinetics equations. The unit can be operated as a complete entity or, alternatively, in two sections for the simultaneous handling of two equations.

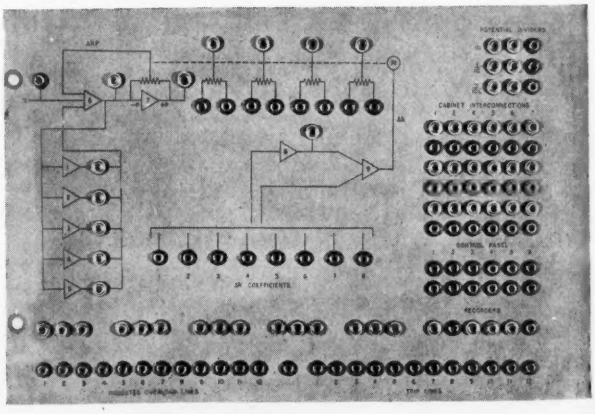
At present 84 amplifying units are installed and provision has been made for a further sixteen. The amplifiers are directly coupled with a range from minus 100 volts to plus 100 volts and are fitted with Bristol's Syncroverter choppers. The long-term drift is less than $\pm$ 100 μ V and the effective grid current is less than 10^{-11} amps. If the output exceeds the limits of $\pm$ 100 volts, integrator inputs are disconnected and the outputs maintain their value for a sufficient length of time for records to be taken of conditions immediately prior to the overload. Coefficients and internal conditions are set in by wire-wound potentiometers. The servo multipliers—twenty in all—are capable, when operating direct from the computing amplifiers, of multiplying up to five quantities.

The reactor kinetics panel is permanently wired for six equations with five groups of delayed neutrons. Delay constants and delayed neutron fractions are set in by manual controls. Terminals to the various circuits are brought out to a series of sockets on a patch panel.

To simulate the effect of coolant transport times from reactor to heat exchanger, a transit time-lag simulator is included with a continuously variable delay ranging from two to sixty seconds. This variation can be adjusted manually or from a computed signal.



Right: View of one of the 84 identical D.C. amplifiers incorporated in the computer. The plug-in unit type of construction makes for easy maintenance.



Patch panel for setting computer conditions.

Problems of Mechanical Analysis in Reactor Technology

by
Dr. G. HORVAY
General Electric Co., N.Y.
recently Knolls Atomic Power Laboratory

In this article some of the analytical problems—in thermal stresses, shells, and perforated sheets—that have been encountered in the SIR Reactor Engineering Section in recent years are described. This approach, of presenting specific cases of interesting and urgent problems, is used as a means of illustrating the challenges the job of a structural specialist offers.

Thermal stresses in thin-walled shells subject to temperature gradients

Beams, plates, and shells of revolution constitute the principal elements of structures which are to carry significant loads. Requirements of strength, economy in material, ease of fabrication, and ease of assembly all favour their selection in preference to others. The loads these elements are expected to carry are of mechanical and thermal origin. Mechanically a beam may be loaded along its axis (in which direction it has great strength if relatively short) or transversely (in which direction its strength is much smaller); plates likewise have much greater strength for in-plane loading than for transverse loads. Shells of revolution will support, because of their hoop action, a larger portion of the load in the form of transverse loads (pressure loads) than will plane structures.

Thermal loads occur when part of a structure is heated, wants to expand, but is restrained by an adjoining structure. Such a case is illustrated in Fig. 1, where the lower portion of a thin-walled cylindrical container of average wall radius a is raised to temperature $\theta=T$. The lower portion wants to increase its radius by $\delta=a\alpha T$ (α is the coefficient of thermal expansion $-10^{-5}/°F$ for austenitic stainless steel), whilst the upper part of the shell, at temperature $\theta=0°$, wants to maintain the original radius. The first effort is successful a distance about 2.5l below x=0, the second about 2.5l above x=0, where $l=.778\sqrt{az}$ and the wall thickness, z is small, say less than a/5. In the in-between region, about 5l wide, a compromise develops, since continuity in radial displacement δ and slope χ must be maintained between upper and lower portions. The transition portion incurs stresses, sketched in Fig. 1, which may become inadmissibly severe when T is large. For brittle materials an excessive T may mean fracture under a single loading; in the case of ductile materials we are primarily concerned with excessive plastic flow and cumulative fatigue damage under repeated loading. We may refer to the above introduced characteristic length l as "attenuation length," because it represents the distance in which actions developing at discontinuities, such as x=0, decay by a factor of e from their edge (x=0) values.

If, instead of acquiring a uniform temperature T, the lower portion or the shell is subject to a linear axial temperature gradient T^1 deg/in., then the lower portion would like to acquire a conical shape of slope equal to $a\alpha T^1$. This conical shape again could be taken on without stresses (linear temperature variations in a homogeneous isotropic body never cause stresses if the deformations are not suppressed) were it not for the restraint exercised by the upper shell portion. The requirement of continuity of displacement and slope between the two shell parts leads to a transition region where the slope is neither that of the lower section, as it is below level $x<-2.51$ approx. nor as it is above level $x>2.51$ approx., but has intermediate values.

If the lower shell portion is subject to a non-linear temperature variation, then stresses will arise not only near the juncture x=0 due to elimination of misalignments between upper and lower portions, but also in the entire lower portion. A non-linear temperature distribution (one which is not of the form $\theta=A+Bx+Cy+Dz$) would like to create deformations which cannot be accommodated by the volume elements (see Fig. 1) z a dθ dx of the shell without interfering with the deformation of neighbouring elements; it is this mutual interference which creates stresses. One should note that for very sharp temperature gradients the hoop stress σ_θ is the dominant stress, while for milder temperature gradients the meridional bending stress σ_x is dominant.

Stresses are caused also when a temperature gradient

$$\theta_r = \frac{To-T_i}{2} + \frac{r-a}{z}(T_o-T_i)$$

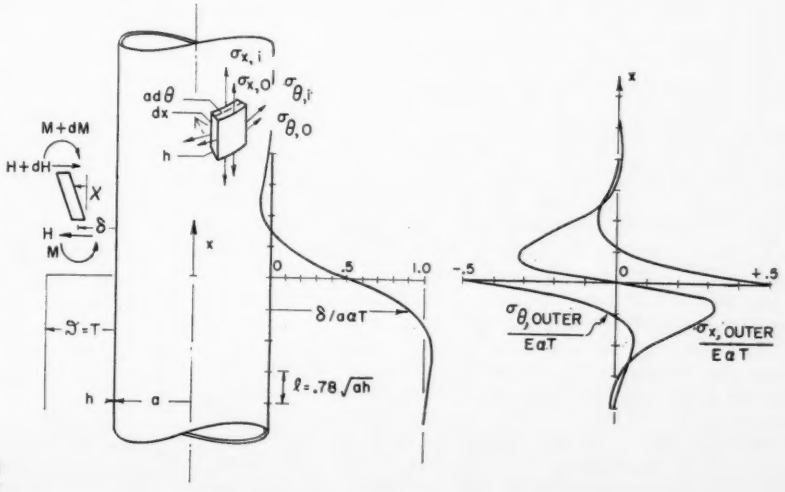


Fig. 1. Stresses in a tube resulting from raising the lower section to a uniformly higher temperature than the lower.

is set up across the wall of a shell (T_i=inner wall temperature, T_o=outer wall temperature). Such a situation arises, for instance, when a thin-walled container containing cold fluid on the inside is heated from the outside, see Fig. 2. Note that the temperature distribution is non-linear in y and z, since $r=\sqrt{y^2+z^2}$. But in the present case the temperature gradient does not manifest itself in deformations, except near the shell ends. Although the hotter outer shell half would like to increase in perimeter, the cooler inner half

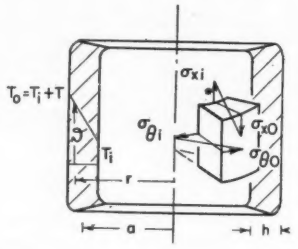


Fig. 2. Distortion occurring in a tube containing cold fluid inside when heated on the outside. Only at the ends is the differential expansion apparent.

would like to contract equally; the two efforts cancel and the shell maintains a size appropriate to the mean temperature $(T_o+T_i)/2$. Only near the ends, where there are no restraints, are the hotter outer fibres able to elongate beyond the cooler inner fibres; this is indicated schematically in Fig. 2.

Dislocations at bolted flange joints

The above described cases of Figs. 1 and 2 are the daily bread of the thermal stress analyst and design engineer. The analytical treatment of these and similar problems, can usually be looked up in company reports, frequently also in textbooks or handbooks. But the minute we pass beyond these simplest cases we are, surprisingly, on virgin territory. Sometimes an obscure magazine article deals with a novel situation, but usually the analysis and the method for the calculation of stresses and displacement has to be established specially. In Fig. 3 a shell with a conical hub and a flange bolted to a plate is illustrated; the assembly is subject to some simple axial temperature distribution, $\theta(x)$. Were the bolts removed the temperature distribution would cause some (readily calculable) angular misaligment χ^* and radial misalignment δ^* to develop between plate and flange.

To suppress such misalignments, moment and shear force reactions M and H must be developed at contacting surfaces of plate and flange, whose magnitudes can be calculated. Whether or not these reactions do develop depends on the preload tension P of the bolts, which furnishes certain "available" moment and shear force M_{avail}, H_{avail}. If these quantities are larger than the calculated M and H, we have a tight joint. If, however, the available moment drops below the required moment M, an angular gap, say γ^*, opens between plate and flange, as illustrated in Fig. 3a—not of the full magnitude χ^* since M_{avail} suppresses part of it, and some of the opening effort goes into extending and bending the bolt. If the available shear force is below the required H, slippage, say Σ^*, occurs between plate and flange, as illustrated in Fig. 3b. Not of the full magnitude σ^* since H_{avail} suppresses part of it, and some of the displacement effort goes into bending and shearing the bolt.

Dislocations (motion of flange relative to plate) are detrimental to proper operation of the container. Dislocations may be responsible for leaks, bolt fatigue, and even for container or plate fatigue. The relative motion of plate and flange may cause, for some materials and media, fretting corrosion; in other instances the mating surfaces may seize, as is often the case with stainless-steel surfaces in the presence of sodium. If such galling takes place in a grossly dislocated position, as in Fig. 3b—say, during a rarely occurring thermal transient—stresses of large magnitude may become locked up in the system. During subsequent normal operation of the system, the cycling of stresses of small amplitude, ordinarily regarded as harmless, may result in a fatigue failure when superimposed on the large residual stresses which are present.

The characteristics of such occurrences do not seem to be described in the literature. These had to be figured out, described and interpreted in order to explain to the design engineer the implications of failures of this kind; he in turn had to figure out ways of getting around the difficulty of re-design of the joint. This he has done in many ways, e.g., by protecting the bolts by shear bushings, by incorporating rabbets in the mating parts, but the use of thermal baffling; frequently by the simple expediency of applying greater preload to the bolts, or by specifying heavier bolting. On other occasions it has been found necessary to ask the power plant engineer to change the thermal programming of the container.

There are further problems one must be on the lookout for in connection with the assembly of Fig. 3. The size of the unbolted plate is determined by its average temperature. The penetration of temperature into a slab of steel during a transient must be considered. Because of its greater heat capacity, the cover plate will come up to temperature, during a start-up transient, more slowly than the rest of the assembly. (And during a shut-down it will return more slowly.) The temperature distribution shown on the left of Fig. 3 is illustrative also of the start-up case. The thermal lags that develop during fast heating of the assembly cause stress problems quite similar to the one discussed earlier.

If the contemplated temperature variations of the above container are rather large it may well be advisable to do away with the weld at the junction of flange and conical hub, and replace the section by a single forged piece, in spite of its greater expense. (The weldment, frequently of higher yield strength than the parent material, introduces a discontinuity into the material properties of the structure in the region of highest stresses. This causes strain localization in the "heat-affected region" which adjoins the weld. The strength of a structure may thus be adversely affected by injudiciously located welds.) The weld near the less exposed knuckle portion of the shell can, undoubtedly, be retained.

Thermal shock. End problems

Consider a long thin metal strip with one of the short edges attached to a very rigid large mass of material. The heavy ring with thin spokes, illustrated in Fig. 4, may be regarded as representative of such a structure. Suddenly the surface temperature of the assembly, originally zero, is lowered ("shocked") T degrees. Such as would occur if the assembly were suddenly dumped into a large fluid bath at

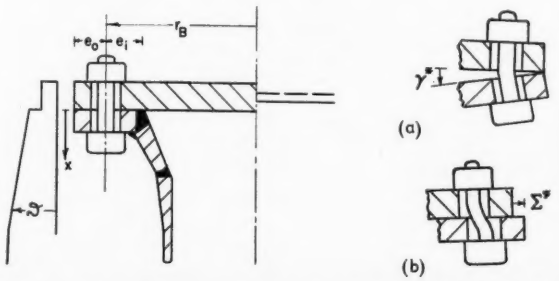


Fig. 3. A shell with a conical hub and flange bolted to a plate subjected to a simple axial temperature distribution. With insufficient preload tension on the bolts condition of (a) angular gap formation or (b) slippage can arise.

$-T$ temperature. The thin strip acquires the temperature $-T$ almost instantaneously, whilst the thick mass is still essentially at 0°. The strip height shrinks by $2z\alpha T$ through most of the strip's length. On the other hand, the rigid connection between strip and mass prevents the edge B'B of the strip from deforming; a short transition region connects the two portions, as illustrated in the figure. One can demonstrate that complete restraint of edge B'B causes, according to elastic theory, infinite stresses at the corners B and B', see Fig. 4 curve (a).

Such problems as the stress determination of the structure in Fig. 4, are seemingly simple ones. They are highly idealized prototypes of a large variety of practical occurrences, so their solutions should be of great practical value. Nevertheless there is no solution available of these problems in the literature. They belong to a class of problems which may be referred to as "end problems," where the strip is not subjected to tractions anywhere, except along the short edge B'B. Here, however, the normal and shear tractions which act (and are of unknown magnitudes in the example of Fig. 4)

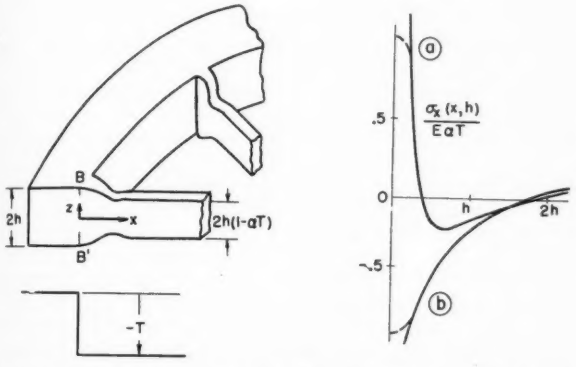


Fig. 4. Thermal stress, produced when a complete unit consisting of a massive rim with thin spokes is subjected to a sudden temperature change, rises to a very high figure at the junctions of the sections.

form a "self-equilibrating system," i.e., have no force and moment resultant. Such a system of stresses has only very localized effects, as predicted by St. Venant in 1855, and demonstrated approximately in reference 6, proven quantitatively in references 7a, b. The stresses will be barely noticeable at a distance $x=2z$ (approx.) from the vertical edge. Nevertheless, their high intensity in the vicinity of B'B may cause fracture if the piece is brittle, plastic strain and fatigue damage if the piece is ductile. A simple problem of this type is solved in reference 8. The solutions developed at KAPL constitute but a first step toward answering the many important questions that relate to a more realistic formulation of this group of problems, where the connection between strip and mass (as it concerns Fig. 4) is not infinitely rigid but merely very rigid and where in the region of large stresses plastic flow may take place. How many shocks of magnitude T can specified engineering materials sustain before cracking when they are supported, say, in semi-rigid fashion, as are the strips in Fig. 4? To what extent do fillets reduce the stresses in the corner? How is behaviour affected by a weld nearby? Some of these problems can be handled analytically, some others are unknown. Some are obviously tasks for the experimenter. All of them are of great concern, because obviously solutions have to be provided or remedies offered for problems of similar nature day after day.

One of the current problems that is of particularly acute concern is the problem of thermal shocking of holes. In contrast to the problems of Fig. 4, this one does not give rise to infinite stresses (not even in theory), so a purely elastic analysis is adequate for its treatment when the shocks are moderate. The surfaces are suddenly chilled, by some liquid into which the plate is dumped from zero, say, to a temperature $-T$. Two cases are of interest: (a) the hole is plugged so that the internal surface of the hole is not subjected to chill, (b) the hole surface is also exposed to the liquid. When chilled, the surface of the plate wants to contract, but the hot subsurface material keeps it extended; so that surface layers incur uniform biaxial tensile stresses

$$\sigma_r=\sigma_\theta=E\alpha T/(1-\nu)$$

at some distance from the hole. The disturbance created by the presence of the hole increases the stresses in the hole's vicinity to a maximum value of $E\alpha T\,k(z)/(1-\nu)$. What is the value of the concentration factor $k(z)$ when the stresses are elastic? What are the strains when part of the hole's vicinity incurs plastic flow? (ν also varies in this case.) To what extent can the stress or strain concentration factors be reduced by suitable chamfering of the holes? Again, some of these questions may be treated analytically, some others experimentally, still others both ways; but they all contain information which must be ferreted out to avoid excessive conservatism in design.

Thermal stresses due to heat generation

Our last example on thermal stresses pertains to the cylinder in which we assume a parabolic temperature distribution $\theta_r=\theta_0(1-r^2/z^2)$ to exist. Such a temperature distribution may develop in a rod when there is internal heat generation. The question has been raised, to what extent does slicing of the cylinder into 60° sectors (and still retaining the foregoing temperature distribution) alleviate the thermal stresses?

Even if it is assumed that the temperature differences involved are fairly moderate, so that elastic analysis applies, there is still an exceedingly intricate mathematical problem to be faced. A reasonably accurate answer to the question would require an enormous expenditure in manpower and machine computing time. But a KAPL analyst is often called on to provide quick estimates for situations which are not readily analysable, or adaptable to simple test procedures. The problem of the cylinder with heat generation is worked out, in rough approximation, as an illustration for the case where "rough and dirty" methods, guided by experience and judgment provide reasonable estimates in little time.

One finds, in terms of the reference stress, $S=E\alpha\theta_0/(1-\nu)$ that away from the end-faces the cylinder stress reaches the maximum value 0.5 S both in the axial direction (σ_z) and the peripheral direction (σ_θ). On the endfaces (z=o, z=l) the peripheral stresses σ_θ reach a magnitude of about 0.7S. The inability of the cylinder to deform (the outer layers of the cylinder restrain the inner layers, and vice-versa, except near the endfaces) is mainly responsible for the large stresses in the complete cylinder. (Representative values, for 347 stainless steel are, $E=28\times10^6$ p.s.i., $\nu=0.3$, $\alpha=10^{-5}$°F, and 28,000 lb./in.^{2} yield stress. Thus a temperature rise of 140°F from surface to axis will initiate yielding.)

When we slice the cylinder into sectors these sectors will bow, with a radius of curvature $R=z/1.24\alpha\theta$ (approx.). This deformation alleviates thermal stresses. One finds the maximum stress in the sector to be about 0.24S. Thus, the improvement in stresses obtained by slicing the cycling into 60° sectors is about three-fold.

Perforated plates

Perforated plates with holes arranged according to an equilateral triangle pattern, for example, Fig. 5, play an important role in heat exchanger apparatus, and their behaviour was exhaustively investigated under stretching (in-plane) loads and bending (transverse) loads in references 14, 15, 16. Qualitatively it is simple enough to explain the behaviour of a perforated plate. The presence of the holes renders the plate more flexible. In deformation the plate

behaves like a solid plate of equal thickness but reduced stiffness. Striking photo-elastic photographs were obtained by R. Guernsey of the General Engineering Laboratory of the General Electric Company, see reference 17. As is well known, the density of the "fringe lines" is proportional to principal shear stress in the same location. It was found that the photo-elastically determined stresses are in surprising agreement with the theoretical predictions, even though the requirement of slow load variation, the basic assumption of our analysis, is flagrantly violated in the load application regions.

The theory of perforated plates was extended to 2-layer plates in reference 15. The bar used for experimental checking had two layers of holes. The upper layer, reaching to a depth of about ½ plate thickness, had wide holes, in the lower half the holes were narrowed to about half the upper diameters. The tests confirmed the adequacy of our theoretical single layer and 2-layer bending formulæ.

Pipe attachments. Thermal baffles. Bellows

Preliminary extensions have been made to the analysis of Hoff and Kempner, in order to establish criteria for the design of pipe attachments to shells. Pipes, by virtue of their thermal expansions and contractions, occasionally apply very large forces or moments to a shell. At the present time only a half-hearted analytical approach may be made to the evaluation of these quasi-concentrated actions. Analysis is not yet sufficiently developed to account for the distorted circular opening of the shell (the intersection of two cylinders is not a plane figure, much less a circle), for the flare and taper of the pipe near the attachment, or for the local inhomogeneity and consequent strain concentrations introduced by a weld in the case of plastic loading. We must still rely on model testing in these problems to a major extent.

Thermal baffles (i.e., loosely-fitted plates) may occasionally be provided around pipe attachments inside a container to assume a large share of the temperature variations which occur (this is their only role; at the same time they must be so designed as to cause minimum interference with the desired fluid flow pattern and heat transfer characteristics) and thus reduce the temperature differences which act on and exist between structural portions of shell and pipe. Bellows may be provided outside of the shell in the pipeline to provide flexibility and thus reduce the pipe reactions. Thanks to some excellent work performed by another consultant, M. Hetenyi of Northwestern University, it can now be predicted quite reliably the performance of welded bellows with slightly arched convolutions (see reference 18). There is still not full insight into the proper design of elbows in pipelines; these likewise frequently have the purpose of providing more flexibility. Conflicting with the desire to increase flexibility in the piping system, to accommodate thermal expansions without overstressing the system, is the necessity of designing equipment of sufficient rigidity to withstand mechanical shock. Although design of piping systems is not usually a KAPL responsibility, an understanding of its principles is incumbent on a structural specialist.

Thermal fatigue cycling

One of the most important props the KAPL analyst has is the simple curve, Fig. 5, which was determined in the Applied Physics Laboratory and shows fatigue life of a hollow tube (illustrated in insert) fixed at the ends, under thermal cycling, as described in reference 19, 20. Coffin correlates fatigue life with strain amplitude by the formula

$$N\epsilon_p^2 = C$$

Here ϵ_p is the plastic strain range (total strain minus elastic strain) incurred by the specimen during a cycle, and N is the number of uniaxial strain cycles the specimen can take before fracture. The constant C on the right is a function of the metallurgical properties of the test piece and depends, amongst others, on finish, defects, strain concentrations, and, in an unexpectedly critical manner, on presence of corrosive agents. Coffin determined the curves N vs ϵ_p for 347 stainless steel under various conditions in a series of careful tests; further studies are now under way toward establishment of appropriate safety factors for practical structures.

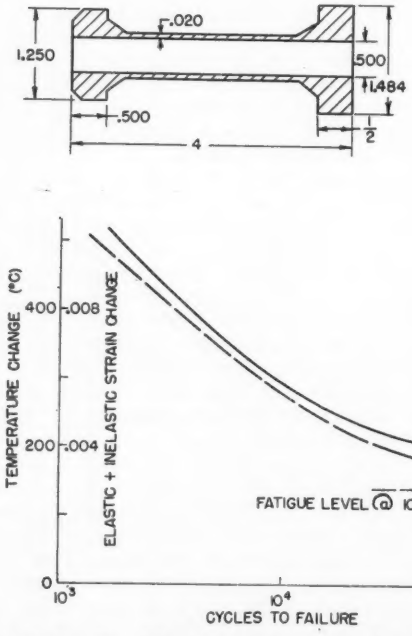


Fig. 5. Fatigue life of the hollow tube with fixed ends shown above determined experimentally. Further studies will lead to the establishment of appropriate safety factors for practical structures.

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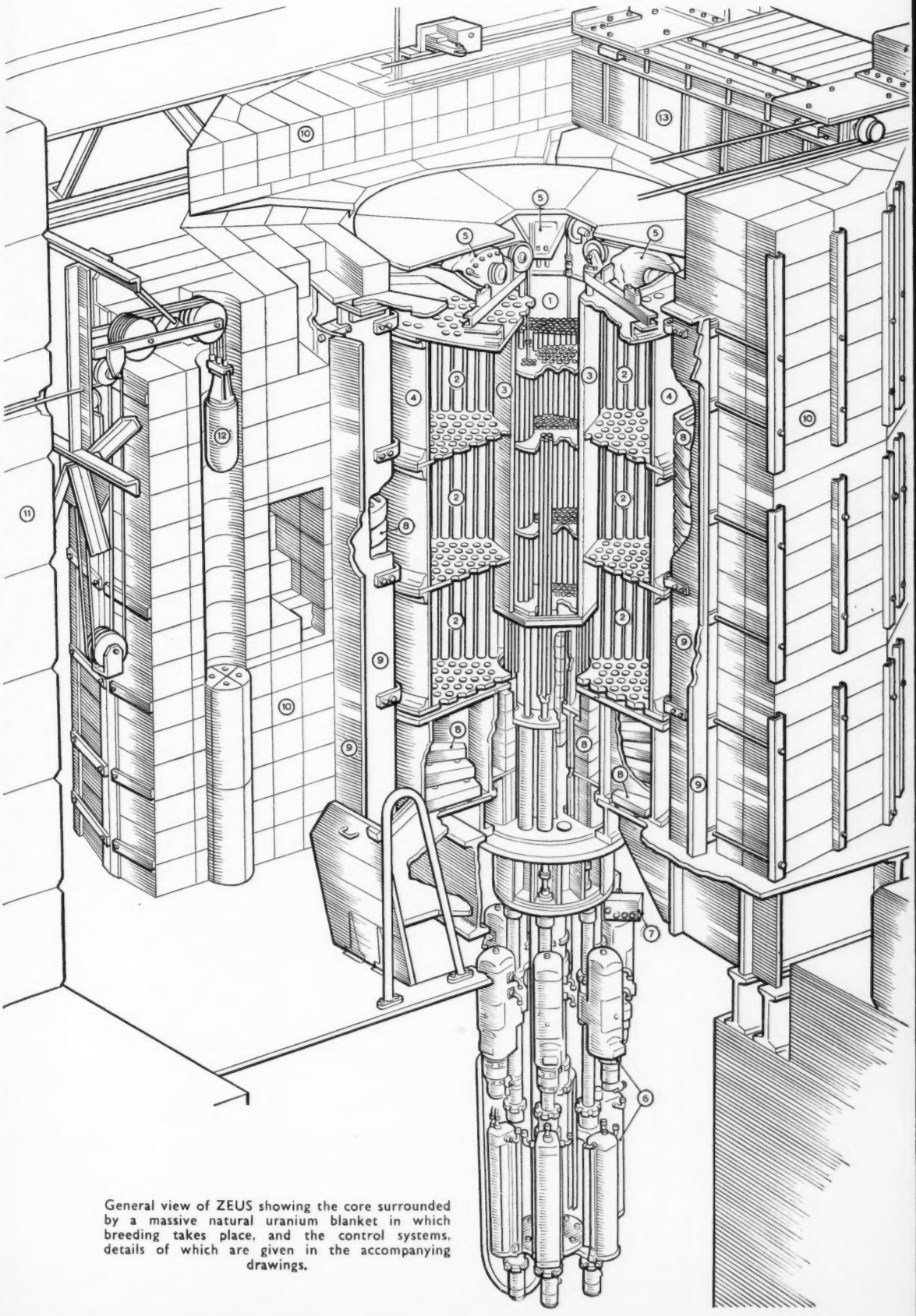
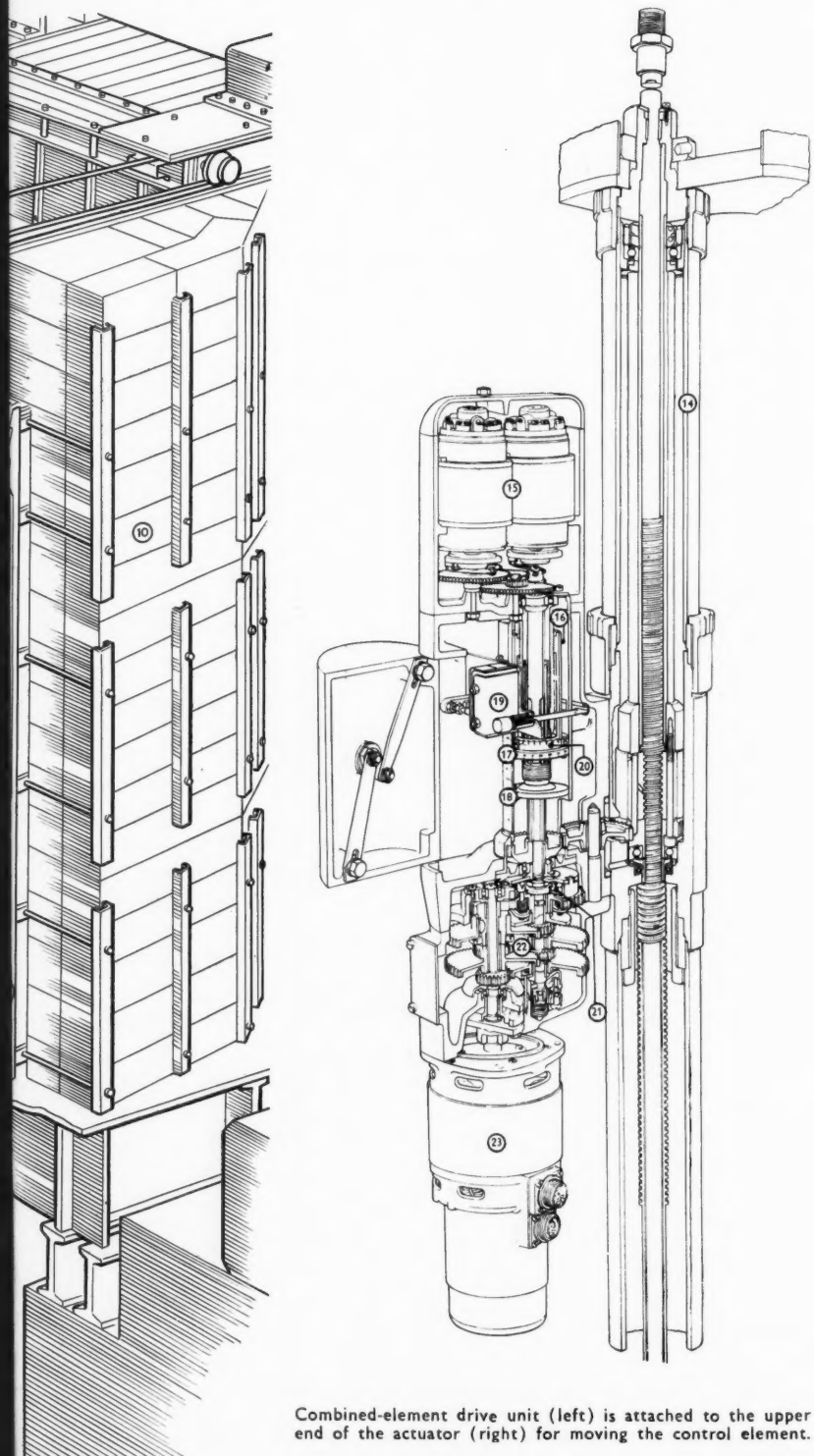


General view of ZEUS showing the core surrounded by a massive natural uranium blanket in which breeding takes place, and the control systems, details of which are given in the accompanying drawings.



Combined-element drive unit (left) is attached to the upper end of the actuator (right) for moving the control element.

KEY

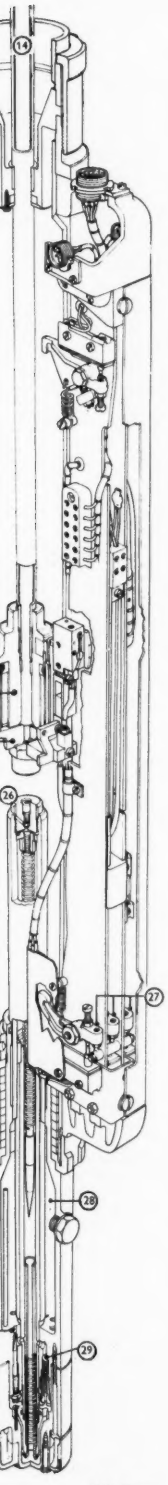
General View

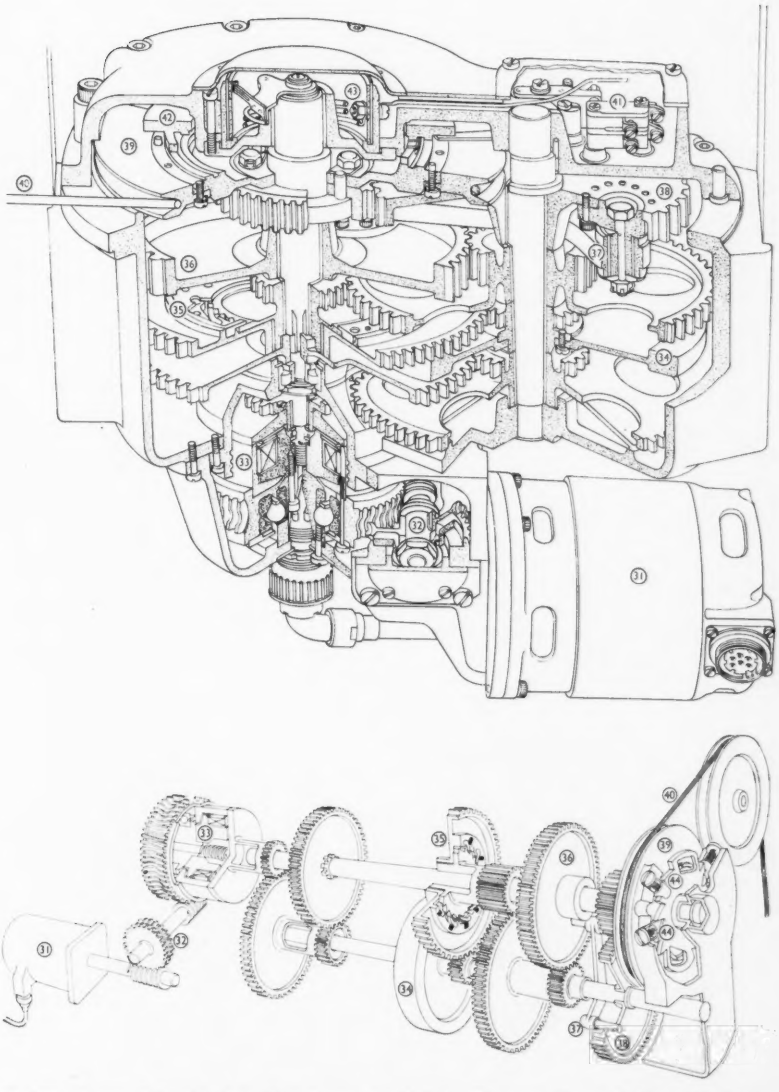
1. Core
2. Blanket
3. Core shell
4. Blanket shell
5. Operating heads for shut-off rods
6. Combined rod drive units
7. Fission chamber head amplifiers
8. Mock coolant
9. Reactor shell
10. Fixed graphite thermalizing shield
11. Biological shield
12. Ion chamber
13. Travelling graphite shield

Combined Element Drive Unit (6)

14. Actuator unit
15. Magslip position transmitters
16. Stop barrel

The World's Reactors No. 5 — ZEUS





Details of one of the six shut-off rod operating heads. They are mounted above the reactor with the shut-off rods suspended by wire cable from the pulley. A simplified view of the gear train is shown in the lower illustration.

17. Stop
18. Striker
19. Top limit switches
20. Anchor pawl and ratchet
21. Friction clutch
22. Reduction gear train
23. Motor

Combined Element Drive Actuator Unit (14)

24. Lifting magnet
25. Armature
26. Damper plunger
27. Bottom limit switches
28. Recuperator chamber
29. Relief valve
30. By-pass orifice

Shut-off element Operating Head (5)

31. Motor
32. Worm reduction train
33. Magnetic clutch
34. Flywheel
35. Ratchet
36. Follower
37. Connecting link
38. Driver
39. Winding pulley
40. Wire cable to shut-off element
41. Limit switches
42. Torque ring
43. Potentiometer
44. Spring plungers

The World's Reactors No. 5

ZEUS — ZERO ENERGY, URANIUM SYSTEM

TYPE:	Fast, heterogeneous.
PURPOSE:	Evaluation of data for final Dounreay design. Dounreay is to be a 60 MW power breeder.
LOCATION:	A.E.R.E. Harwell, England.
OPERATION:	Commenced operation December 22, 1955.
FUEL:	Natural uranium and enriched uranium. Enriched uranium: 45% U 235. Fuel form: small cylinders, 0.9 in. O.D. Core enrichment varied by altering U 238/U 235 ratio. Total core investment: 1 ton.
CANNING:	Fuel not canned. Elements constructed by loading cylinders into long Al tubes.
CORE:	Over-all dimensions: 20 in. × 20 in. hexagonal cylinder. Number of fuel channels: 307. Lattice: hexagonal, 1 in. pitch.
BLANKET:	Natural uranium. Form: bars of U in Al tubes. Over-all dimensions: 8 ft. × 6 ft. dia. Total investment: 50 tons.
COOLANT:	None. Dounreay sodium simulated by solid Mg and Al bars.
POWER:	Maximum: 100 W.
CONTROL:	Geometry of 84 fuel elements in 12 groups of 7. 6 groups lifted in from above. 6 groups pushed in from below. 2 of these used for fine control. All returned (out) by gravity for shut-down.
SHIELDING:	Graphite: 2 ft. thick as neutron shield around blanket. Concrete: 2 ft. thick.
OVERALL SIZE:	28 ft. x 22 ft. x 16 ft. high.

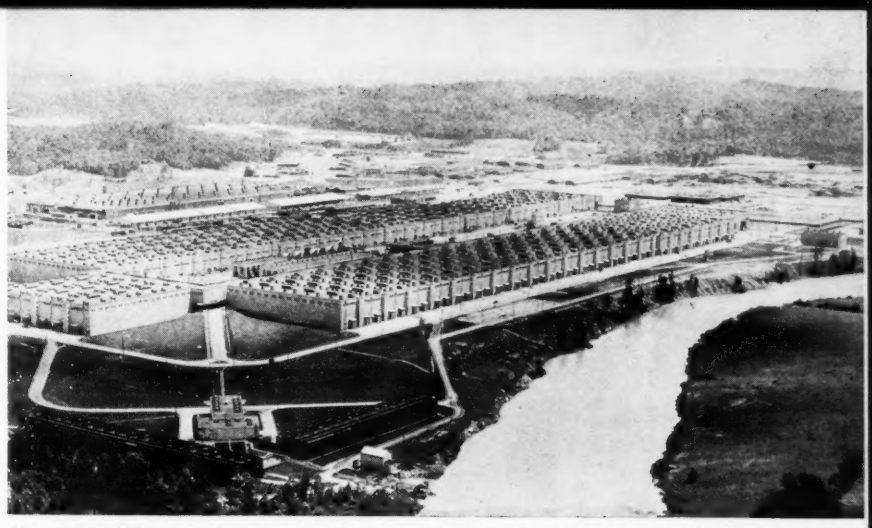
NOTE: Further physical constants will be made known in two or three months time, and will be published when available.

A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. each).

Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. BEPO (April, 1956).
No. 2. CP5 (May, 1956).
No. 3. NRX (June, 1956).
No. 4. DIMPLE (August, 1956).

Activities of the U.S.A.E.C.



Oak Ridge National Laboratory, which is responsible for the bulk of America's radio-isotope production. The Oak Ridge Institute for Nuclear Studies is located nearby.

Structure of the Commission

THE United States Atomic Energy Commission came into being as the result of the Atomic Energy Act of 1946, in which provision was made for certain interests, properties and facilities of the Manhattan engineering project to be transferred to the Commission from January 1, 1947.

As with the U.K. Atomic Energy Authority the Commission is strictly a committee. It consists of five members, one of whom is designated chairman and all are appointed by the President with the advice and consent of the Senate. The commissioners are responsible for the organization of Government-sponsored atomic energy research and for taking decisions on matters of policy and administration.

The original Atomic Energy Act was modified in 1954 to take into account the change in emphasis from military to peaceful applications and served to permit the declared policy of the U.S. to take form. This provides that, subject to the paramount objective of making the maximum contribution to common defence and security, the development, use and control of atomic energy should be directed so as to promote world peace, improve the general welfare and increase the standard of living and promote free competition and private enterprise.

The act provides for three permanent committees—a general advisory committee, military liaison committee, and a joint committee on atomic energy. The general advisory committee is appointed by the President and consists of nine civilians who advise the Commission on scientific and technical matters relating to materials, production and research and development. The nine are

Dr. I. I. Rabi, chairman: Professor of Physics, Columbia University. Dr. Jesse W. Beams, Professor of Physics, University of Virginia. Dr. J. B. Fisk, executive vice-president, Bell Telephone Laboratories, Murray Hill, New York. Dr. Warren C. Johnson, Dean of Physical Sciences, University of Chicago. Dr. Edwin M. McMillan, Professor of Physics, UCRL, Berkeley, California. Eger V. Murphree, president, Esso Research and Engineering Co., New York. Dr. J. C. Warner, president, Carnegie Institute of Technology. Walter G. Whitman, head, Department of Chemical Engineering, Massachusetts Institute of Technology. Dr. Eugene P. Wigner, Professor of Physics, Princeton University. *Secretary:* Dr. Jane H. Hall, assistant director, Los Alamos Scientific Laboratory, Ucla, Los Alamos, New Mexico.

The military liaison committee comprises seven members from the defence department. Co-operation between the Commission and the defence department on atomic energy matters from the military point of view is conducted through this committee. Its responsibilities include the allocation of special materials for research, the control of information relating to the manufacture and utilization of nuclear weapons, the development, manufacture, use, storage of these weapons.

The joint committee on atomic energy is responsible for liaison between the Commission and the Senate and House of Representatives. Nine members from each House sit on the committee and make continuous studies of the activities of the A.E.C. and of problems relating to development, use and control of atomic energy.

In addition to the three committees detailed above provided for in the act there are a number of additional technical and advisory committees which have been formed to advise the Commission on technical problems. Members are recruited from industry, universities, trade unions, etc.

Objects of the Commission

The major programme of atomic energy development specified by the Act is as follows:

1. A programme of conducting, assisting and fostering research and development in order to encourage maximum scientific and industrial progress.
2. The dissemination of unclassified scientific and technical information and for the control, dissemination, and declassification of restricted data, subject to appropriate safeguards, so as to encourage scientific and industrial progress.
3. The Government control of the possession, use, and production of atomic energy and special nuclear material so directed as to make the maximum contribution to the common defence and security and the national welfare.
4. To encourage widespread participation in the development and utilization of atomic energy for peaceful purposes to the maximum extent consistent with the common defence and security and with the health and safety of the public.
5. International co-operation to promote the common defence and security and to make available to co-operating nations the benefits of peaceful applications of atomic energy as widely as expanding technology and considerations of the common defence and security will permit.
6. Administration which will be consistent with the foregoing policies and programmes, with international arrangements and with agreements for co-operation, which will enable the Congress to be currently informed so as to take further legislative action as may be appropriate.

Lewis L. Strauss, chairman of the U.S. Atomic Energy Commission.

The bulk of the work undertaken by the Commission is carried out largely by industrial concerns and by private and public institutions under contract to the Commission, a number of production, research and development activities are conducted by contractors in facilities owned by the Commission. This is at variance with the system adopted by the U.K.A.E.A. where, although a considerable amount of development work quite apart from manufacturing work is contracted out to industry, the facilities owned by the A.E.A. are also operated by its own staff.

Members and Officials of the A.E.C.

Members

Chairman	Lewis L. Strauss
	John Von Neumann
	Harold S. Vance
	Willard F. Libby
	Thomas E. Murray

Officials—Washington Headquarters

General Manager	K. E. Fields
Deputy General Manager	R. W. Cook
Assistant General Manager for Admin.	R. E. Hollingsworth
Special Assistant—Liaison	Paul F. Foster
Director, Division Office of International Affairs	John A. Hall
Special Assistant—Congressional Relations	Bryan La Plantle
General Counsel	William Mitchell
Controller	Don S. Burrows
Director, Div. of Civilian Application	Harold L. Price
Director, Div. of Inspection	Curtis A. Nelson
Chief, Office of Operations Analysis	Dr. Paul Fine
Secretary to the Commission	W. B. McCool
Director, Div. of Military Application	Brig. Gen. A. D. Starbird
Assistant General Manager for Research and Industrial Development	A. Tammaro
Director, Div. of Biology and Medicine	Dr. Charles L. Dunham
Director, Div. of Reactor Development	W. Kenneth Davis
Director, Div. of Research	T. H. Johnson
Assistant General Manager for Manufacturing	David F. Shaw
Director, Div. of Construction and Supply	John A. Derry
Director, Div. of Production	E. J. Bloch
Director, Div. of Raw Materials	Jesse C. Johnson
Assistant General Manager	Harry S. Traynor
Director, Div. of Classification	Charles L. Marshall
Director, Div. of Information Services	Morse Salisbury
Director, Div. of Intelligence	C. H. Reichardt
Director, Div. of Organization and Personnel	Oscar S. Smith
Director, Div. of Security	John A. Waters
Director, Div. of Nuclear Materials Management	D. F. Musser

Field Offices

Manager, Chicago Operations Office	J. J. Flaherty
Manager, Grand Junction Operations Office	Allan E. Jones
Manager, Hanford Operations Office	James E. Travis
Manager, Idaho Operations Office	Allan C. Johnson
Manager, New York Operations Office	Merrill I. Eisenbud
Manager, Oak Ridge Operations Office	S. R. Sapirie
Manager, San Francisco Operations Office	Harold A. Fidler
Manager, Albuquerque Operations Office	Kenner F. Hertford
Manager, Savannah River Operations Office	Robert C. Blair
Manager, Schenectady Operations Office	Jon D. Anderson

The General Manager, appointed by the Commission, is the principal executive and administrative officer of the Commission. He is responsible for over-all management of the A.E.C. within the policies established by the Commissioners. Principal assistant to the General Manager is the Deputy General Manager. The General Manager is also assisted in his executive and administrative duties by the Special Assistant-Liaison, the Assistant General Managers for Administration, Research and Industrial Development, Manufacturing, the Assistant General Manager, the Director, Division of Military Application and the several divisions which report to the Assistant General Manager. In addition, certain Staff Division and Offices report directly to the General Manager and assist him in their functional areas.

The Assistant General Manager for Administration assists the General Manager in over-all management of the A.E.C. with primary responsibility for furnishing day-to-day administrative direction and co-ordination to all programme and supporting activities of the Commission.

The Special Assistant-Liaison assists the General Manager by co-ordinating and directing the activities of the Division of International Affairs and the Special Assistant, Congressional Relations.

The Assistant General Manager for Research and Industrial Development assists the General Manager by co-ordinating and directing the activities of the division of biology and medicine, reactor development and research.

The Assistant General Manager for manufacturing assists the General Manager by co-ordinating and directing the activities of the division of construction and supply, production and raw materials.

The Assistant General Manager assists the General Manager by co-ordinating the activities of the divisions of classification, information services, intelligence, organization and personnel, security and the division of nuclear materials management.

The Director, Division of Military Application, assists the General Manager by directing the activities of the Division of Military Applications.

The Staff Divisions and Offices reporting directly to the General Manager include the Office of Operations Analysis, the Division of Finance, the Division of Inspection, and the Division of Civilian Application. The office of the General Counsel provides legal advice and assistance to the General Manager and the Commission.

20th Semi-Annual Report

THE 20th semi-annual report of the U.S.A.E.C. covering the period January-July, 1956, was presented to Congress on July 31. It emphasizes the growing development of the peaceful uses of nuclear energy, particularly in respect of international relations and agreements: the highlight of the period being the announcement that 20,00 kg of U 235 was to be available for industrial power development in the U.S. and another 20,000 kg for export.

Reactor Development

Under the Power Demonstration Programme the A.E.C. signed a contract with the Yankee Atomic Electric Co., on June 6, for assistance with the company's proposed 134 MW pressurized water reactor. The other two proposals, received in response to the Commission's first invitation in January, 1955, are in course of contract negotiations: these are the Consumers Public Power District of Columbus (75 MW sodium graphite) and Power Reactor Development Co., Dresden, Ill. (100 MW boiling water). A fourth proposal, that of the Consolidated Edison Co. required no government assistance and is one of six projects to be built entirely by industry.

In response to the Commission's second invitation the following seven proposals were received:

Chugach Electric Association, Inc., Anchorage, Alaska, jointly with Nuclear Development Corp. of America, White Plains, N. Y. (10,000 kW liquid sodium-cooled heavy water-moderated). City of Holyoke Gas and Electric Dept., Holyoke, Mass. (15,000 kW gas-cooled [nitrogen]). City of Piqua, Ohio (12,500 kW organic-moderated). Orlando Utilities Commission, Orlando, Fla. (25,000 to 40,000 kW liquid metal fuel). Rural Co-operative Power Association, Elk River, Minn. (22,000 kW boiling water). University of Florida, Gainesville, Fla. (500 kW pressurized light water). Wolverine Electric Co-operative, Big Rapids, Mich. (10,000 kW aqueous homogeneous)

The Rural Co-operative and Wolverine proposals were approved in April as bases for contract negotiations; the other five are being evaluated on a competitive basis contingent upon the availability of funds.

During the period under review the A.E.C. went ahead with

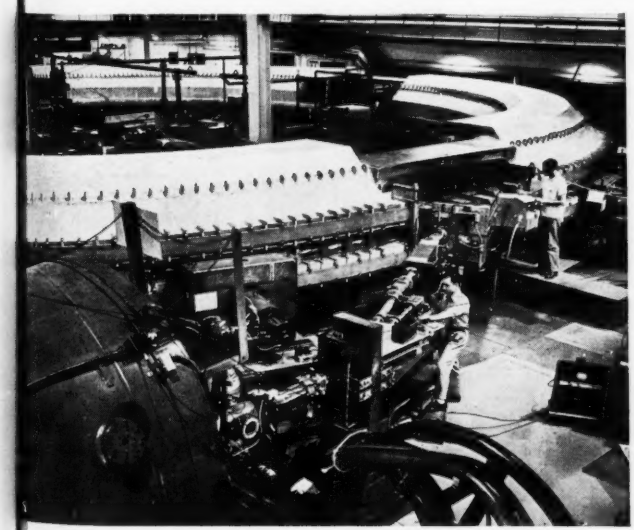
four additional concepts. These included a contract with Atomics International for the Organic Moderated Reactor Experiment (OMRE) and negotiations with Babcock and Wilcox for a Liquid Metal Fuel Reactor Experiment (LMFRE). Outlines for research into the use of plutonium-enriched uranium fuel was requested of the General Electric Co. with a view to freeing some foreign countries of the necessity of importing U^{235}. Study contracts were also negotiated with Ford Instruments Co. and Studebaker-Packard Corp. for work on gas-cooled reactors suitable for the direct driving of gas turbines. Of the other projects in hand, the Commission reports good progress with PWR at Shippingport, and delays in the progress of SRE which were due to the use of the wrong type of welding rod in the fabrication of the tank and other components, and the appearance of small cracks in the end plate of the zirconium cans used for cladding the graphite. Borax-3 was shut down in April to allow a new core of oxide fuel elements to be installed.

At Argonne conceptual design of EBR-2 was completed. A duplicate of ZPR-3, which is being used to obtain data for EBR-2, may be built at Argonne. The construction of the Homogeneous Reactor Experiment (HRE-2) at Oak Ridge was completed in May as was the Los Alamos experiment (LAPRE-1). Top priority was also given to ETR at NRTS, Idaho, which will provide irradiation facilities in the development of reactor components.

Military Programme

The design of the Submarine Advance Reactor (S3G) was completed and construction of the test site for the land prototype begun. Two of these reactors will be used in a radar picket submarine, the largest to be built in the U.S.A. Work is also proceeding on the development of a small submarine reactor (S1C) and a large ship reactor (A1W), whilst the Commission assigned to Knolls Laboratory the design of an organic reactor experiment in connection with the need for a small power plant for light naval vessels.

The army programme includes three major projects—APPR, ALPR, and the Food Irradiation Reactor (FIR). Preliminary steps have been taken in the development of gas-cooled reactors, the work being done by Battelle. Complementary to the Commission's programme, the Army is also studying the use of the closed-cycle gas turbine with nuclear reactors.



The cosmotron at Brookhaven is being used to study the production of heavy mesons and hyperons in hydrogen. An intense proton beam is extracted from the cosmotron and directed on to a liquid hydrogen target placed outside the accelerator.

Metals and Materials

During the period the A.E.C. asked industry to be ready to process spent fuel elements, signed contracts for increased production of zirconium and urged industry to take over production of certain reactor materials, such as boral.

The price that the A.E.C. will pay to licensees for plutonium metal and U^{233} as metal or uranyl nitrate was announced to holders of permits for access to classified information. A revised basic price for thorium of $43 per kg was established in January. Tenders for the supply of reactor-grade beryllium by industry were received.

The U.S.A. is now the leading producer of uranium ore with an output approaching 3 million tons p.a. In May, the A.E.C. announced a new 5-year programme for guaranteed purchasing to take effect on the expiration of the present guarantee in 1962. The base price will be $8 per lb. for U_3O_8 in concentrates that comply with specifications.

Ore production exceeded processing capacity, but three new mills nearing completion will help to reduce stocks.

With the completion of the gaseous diffusion plant at Portsmouth, Ohio, and the initial operations of a new chemical separation plant at Hanford, the Commission has now in production all the additional facilities authorized in July, 1952. Manufacturing facilities therefore comprise three gaseous diffusion plants for the production of enriched uranium, and eight graphite-moderated reactors at Hanford and five D_2O-moderated reactors at Savannah River, for the production of plutonium.

Chemical Engineering

Details are given in the report of work on the separation of fission products from spent fuel elements, including the pyro-metallurgical method, and the substitution of a continuous dissolving method for batch processes. Studies were also undertaken on gaseous forms of neptunium and plutonium, high-temperature properties of uranium dioxide, and the nuclear chemistry of transuranic elements.

Metallurgy

Studies are being carried out on lattice irregularity caused by irradiation, the addition of zirconium to liquid metals to prevent the dissolution of the steels used for the piping, and refining processes for high purity uranium metal.

Physics

During the first half of 1956 a predicted, but elusive, particle, the neutrino, was discovered; the properties of the anti-proton were investigated, and low energy resonances of neutrons released by plutonium fission were measured.

Access to Information

The A.E.C. continued its scrutiny of classification policy and classified material, an increasing volume of non-classified and classified technical information being made available. Applications for licences to construct and operate atomic facilities and requests by industry for access to classified information continued to increase. Under the latest Declassification Guide, 11,000 of 30,000 technical reports studied were removed from classification and a further 8,000 reduced.

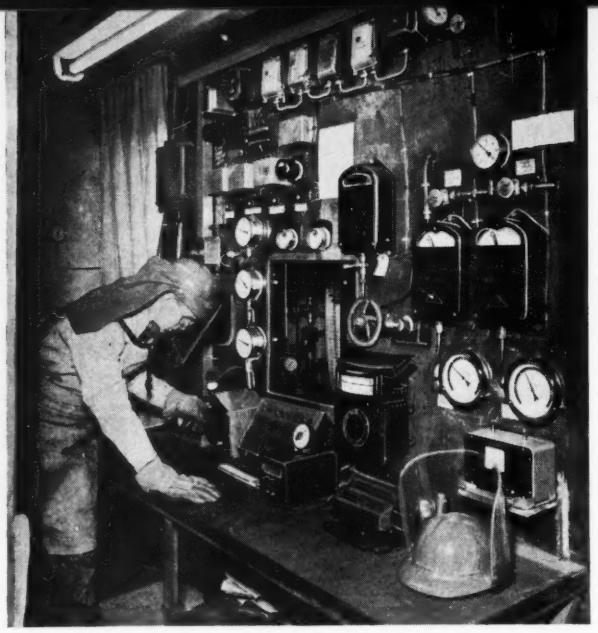
International Affairs

As a result of the agreement reached by the 12 sponsoring countries on the peaceful uses of atomic energy, 87 nations are invited to attend a conference in New York in September with a view to forming an international agency.

At June 30, the U.S. had completed agreements for co-operation with 36 nations, of which 30 are now effective. At that date, research reactor agreements were being negotiated with Ceylon, Ecuador, Guatemala, South Africa, Haiti and Yugoslavia. Power reactor agreements were completed with Australia, France, Netherlands and Switzerland and were being negotiated with Brazil, India, Italy and Norway. During June, the areas of exchange of information between U.S.A., Canada and the U.K. were broadened.

Liquid Metals

Many processes which have been developed specifically for atomic energy applications will be taken over and further developed by other industries. The extension of the use of sodium-potassium as a heat transfer medium to conventional chemical engineering fields can lead to considerable advances in the overall technology.

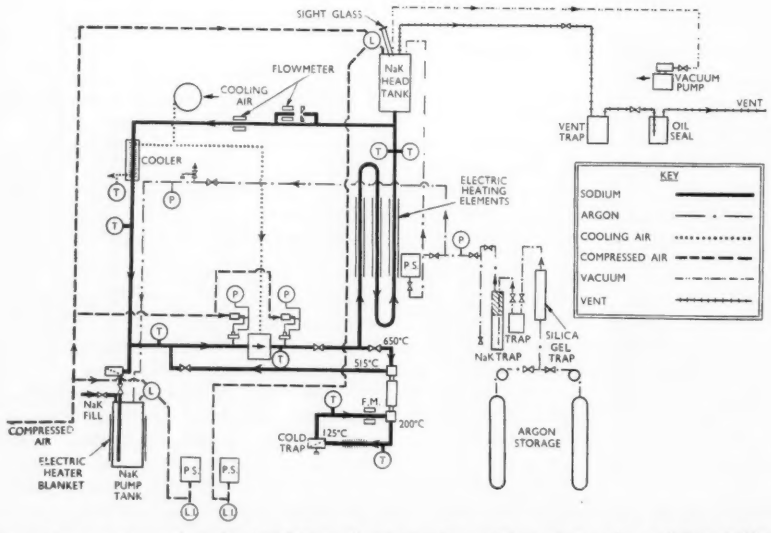


Control and instrument panel for the experimental Na-K loop. The operator has just returned from making an adjustment to the loop itself—hence the helmet and gloves.

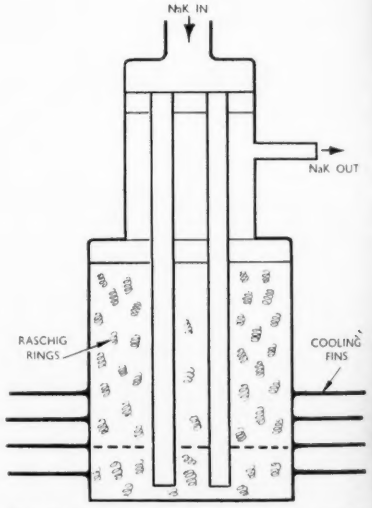
RESEARCH into the use of liquid metals as heat transfer media has been initiated largely by engineers concerned with the removal and utilization of heat generated in nuclear reactors. Attention now, however, is not solely devoted to the atomic energy field and liquid sodium circuits are being investigated with a view to their application in many industrial processes involving heat transfer problems. Experience gained in these additional fields is likely to expand the technology of liquid metals considerably so that by the time liquid metal cooled reactors become a commercial proposition a considerable background of experience will have been formed. Many of the processes under investigation at the present time will serve as useful intermediary stages before the application of liquid metals to reactor cooling, in that whilst the processes involve similar heat transfer problems compatibility specifications will not be so stringent and the results of a failure not nearly so tragic. Initially stainless-steel will be used almost universally in the circuits but experiments are in hand to determine the feasibility of substituting parts of the circuit with mild steel and it can be expected that later work will deal with the advisability of utilizing zirconium and niobium metals and alloys.

A typical chemical engineering application is the removal of heat during the oxidation of naphthalene to phthallic anhydride, a strongly exothermic reaction. It is common practice at present to use diatherm as the heat transfer medium and the temperature at which the reaction can be allowed to take place is therefore limited. There are reports that the optimum temperature is in the region of 400°C and liquid sodium or sodium-potassium alloy would appear to be an ideal heat transfer medium. In the chemical processes where temperatures in excess of 350°C obtain, the cooling medium at present employed is either air or a mixture of fused salts. This applies to fixed bed processes, whereas fluidized processes are invariably cooled by air. When using liquid metals it is more satisfactory to work with a continuous process if the chemistry of the reaction permits but in, for example, polymerization plants, batch operation is necessary. There is however still a strong argument in favour of a liquid metal as coolant in that although the operating temperature is a maximum of 300°C and diatherm is therefore applicable the leeway in operating temperature is small and local hot spots are liable to cause decomposition of the coolant. Since February of this year, when the A.P.V. Co. Ltd. of Crawley, Sussex, announced their interest in the design and construction of liquid metal heat transfer circuits for industrial processes, 13 enquiries have been registered, all concerning plant divorced from the atomic energy field.

Quite apart from the use of sodium as a reactor coolant in nuclear engineering, liquid metal techniques are likely to be



Test loop to determine the feasibility of substituting mild steel for the stainless tubing normally used. Level gauges and pressure switches protect the circuit against mishap. Concentration of dissolved Na_2O is determined visually and by a cooled venturi method.



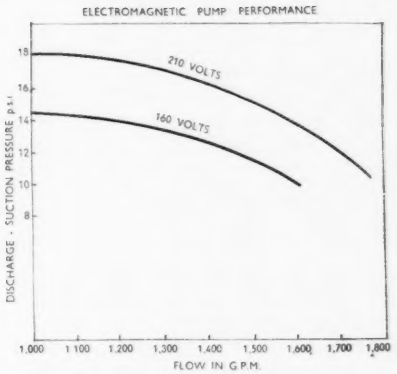
Detail of the cold trap used for purifying the Na-K alloy. Copper forming on the lower vessel allow the liquids to cool below the solution temperature. Raschig rings scrub out the precipitate.

Heat Transfer Media

of value in improving the efficiency of gas turbines. Gas to sodium heat exchangers are under consideration for utilizing the turbine exhaust heat where a small back pressure can result in considerable power loss. This may be of particular importance for closed-cycle gas turbine applications. Appropriate heat exchangers using liquid metals may also prove of value in the re-heat stages. Similarly in steam turbines considerable cost can be saved by providing re-heat of the turbine by a sodium heat exchanger, eliminating as it does a considerable length of high pressure tubing.

One of the most important disadvantages of using sodium as a heat transfer medium is the great weight of stainless steel obtaining in present designs. If the bulk of this stainless steel can be replaced by mild steel a great saving in cost can be made although in some cases compatibility with the sodium may not be the critical feature. However, there would still be an argument for the use of clad steels with a consequent saving in stainless steel weight. An experimental loop set up at A.P.V. to determine the effects of using a mild steel circuit is shown in Fig. 1. The basic circuit in 1-in. piping comprises an electro-magnetic pump feeding sodium through three loops of mild steel piping heated by rod-type elements clamped to the walls. The circuit returns via an electro-magnetic flow-meter through an air cooler for rapid cooling of the circuit, if necessary, back to the pump. The pump is a Frazer-Nash electro-magnetic induction pump single phase A.C., manufactured by Palatine Tool and Engineering Company. Fig. 3 shows the suction pressures and flow rates at two operating voltages. Extreme accuracy is not claimed for this curve as calibration of the electro-magnetic flow meters may not be exact.

An electrically-heated main dump tank is fitted in the circuit which is kept under a small pressure of argon. The circuit is filled by partial evacuation and by increasing the argon pressure in the dump tank. A float-type indicator in this tank prevents overfilling of the system and the inclusion of argon bubbles. At the top of the loop is a header tank also fitted with a float type indicator and sealed by argon. The tank is fitted with a sight glass

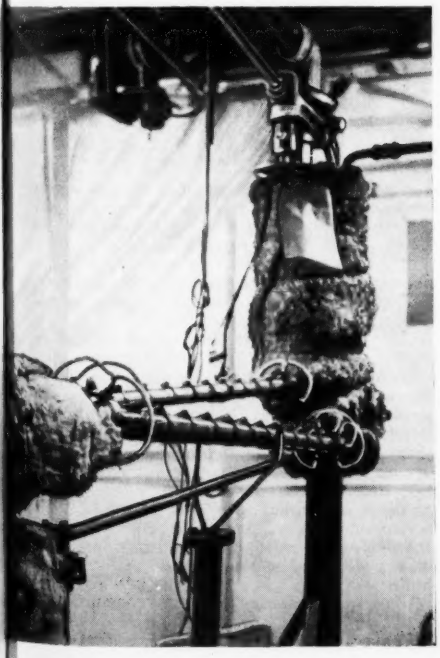


Performance data of the Frazer-Nash E.M. induction pump. High accuracy is not claimed for the alscisor scale due to possible proportional errors in flow meter calibration.

consisting of a rubber-mounted glass plate on an air-cooled extension tube for observation of the surface of the sodium. Small inclusions of sodium-oxide in the liquid can be detected by the bloom on the surface. Provision is made for determining the concentration of sodium-oxide in the metal by including in a by-pass circuit a venturi, which can be cooled, and a flow meter. This system, which was first developed in the United States consists in slowly lowering the temperature through the bleed whilst at the same time watching the flow meter reading. When this reading shows a marked drop the sodium-oxide is solidifying out and blocking the venturi tube. The temperature at which this occurs gives the concentration of sodium oxide in the liquid.

Continuous purification of the solution is accomplished by bleeding off a proportion of the flow through a cold trap. The bleed is fed through a recuperator unit and finally into the cold trap itself (Fig. 2) where the metal passes down the centre tubes to a vessel fitted with radial fins out through the scavenger unit filled with raschig rings, recovering heat from the incoming flow on its way past the inlet. Contamination of the circuit is avoided by fitting the head tank with a vent trap and oil seal and the argon is purified by passing through a sodium-potassium trap and a splash trap.

Other research facilities include thermocouples, recording pressure gauges and additional flow meters. Interlock systems ensure that faults will shut off the heating elements and the electro-magnetic pump. In this experimental circuit it is proposed to use 22/78 Na-K alloy with a freezing point of $-12^{\circ}C$ to eliminate the necessity of providing permanent heating units. In industrial applications it is more probable than a 50/50 mixture would be used which is considerably cheaper and which has a freezing point of $+11^{\circ}C$.



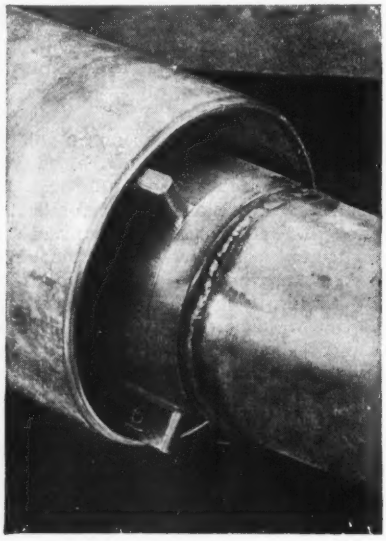
Mild steel insert in the liquid metal loop. Tubes which are butt welded are heated by rod-type elements clamped into position by stainless-steel foil and Jubilee clips. Note protective fibre-glass curtain in background.

Utilization

Whilst the design and construction of metal to metal heat exchangers involve the application of techniques already very well known, sodium to other materials—particularly water—presents unusual difficulties in design and in the evaluation of design philosophy. The heat exchangers for example in the Dounreay reactor are double skinned to eliminate any possible leakage of sodium into the higher pressurized water system. Whilst a double skin may be considered desirable from the safety angle the complication and cost of construction are considerably increased and the A.P.V. Company is establishing a precedent in constructing a single skin evaporator unit for the utilization of heat transferred in processes such as those described above.

One second-skin system comprises a coil welded or brazed to the inner sodium tube, carrying a low-melting-point eutectic unreactive both with water and sodium, fitted with leak detectors to give early indication of wall failure. An alternative system under examination utilizes the Al-Fin process originally developed by Fairchild Aviation and now operated by Wellworthy Ltd., under licence, of bonding

aluminium and stainless steel to give excellent surface contact whilst preventing penetration of the aluminium into the steel. Aluminium is cast round a network of stainless-steel tubes, thus providing three independent materials between the two fluids, but difficulties arise when large-scale units are involved. Much research must be undertaken to determine the effect of a sudden influx of water or steam into a sodium circuit before a fair assessment can be made of the absolute necessity of double-skinned evaporators for reactor applications. Accidents have occurred in loops and preliminary data indicate that, provided adequate pressure-sensitive controls



Typical liquid metal-heat exchanger as used in the primary to secondary circuit at Dounreay.

are installed, the trouble can be confined and repair may not be out of the question.

The advantages in using a single skin heat exchanger are obvious and only experience will prove whether continuous satisfactory operation can be obtained. There is no question, however, that the double skin system will in many cases eliminate the use of sodium-potassium coolants for industrial processes which would otherwise benefit from their use.

Whilst it is not envisaged that the use of liquid metals as heat transfer media in industrial plants will introduce any serious problems from the point of view of external fire hazard and insurance, considerable precautions have to be taken in research facilities. The experimental arrangements described are housed in a building with the walls and roof made of $\frac{1}{4}$ in. mild-steel plate giving a fire duration of 2 hours. The floor is 14-gauge mild steel plate laid on a concrete base, to avoid any possibility of sodium coming into contact with concrete because of the high reaction rate. Steel trays are also provided under the loop. In case of spillage on personnel, who must then be prevented from coming into contact with water, a second building of conventional construction surrounds the working laboratory. Two exits are required leading from the laboratory, and double doors to prevent smoke filtering into the outer building. In the laboratory the main loop is separated from the controls by a steel panel and fibre-glass screens; fibre-glass screens are also hung around the loop itself to direct any spillage into the splash trays. Operators working on the loop are compelled to wear boots, leggings, gloves and helmet and even behind the operating panels goggles and gloves are worn. Whilst any form of spillage is undesirable fire dangers are not as great as was anticipated at the beginning of sodium research and a considerable amount of evidence has accumulated to show that pure sodium particularly will merely form a mildly smouldering mass on the floor. Sodium-potassium alloy is slightly more difficult to deal with in that it continues to burn in its liquid form at room temperatures.

Les métaux liquides en tant que moyens de transfert de chaleur

Les alliages de sodium et sodium-potassium font actuellement l'objet de recherches quant à leurs propriétés en tant que moyens de transfert de chaleur non seulement pour le refroidissement direct de réacteurs nucléaires, mais aussi pour l'emploi dans un grand nombre de procédés industriels. Les exemples comprennent l'oxydation du naphthalène à l'anhydride phthallique qui possède une température optimum de fonctionnement d'environ 400°C et les procédés de polymérisation bien que température d'opération soit plus basse et qu'un système de "fournée" ou lot soit habituellement employé.

Pour réduire le coût des grands circuits d'acier inoxydable, l'emploi d'acier doux est en train d'être étudié pour déterminer les taux de corrosion dans une boucle expérimentale par A.P.V. Co. Ltd., de Crawley, Sussex.

Des économies considérables pourront aussi être réalisées en prévoyant des échangeurs de chaleur avec des parois uniques au lieu du système à doubles parois adopté dans les échangeurs de chaleur "sodium-à-eau" Dounreay. On illustre et décrit un évaporateur à paroi unique à film tombant dans lequel la vapeur se forme dans des tubes à pression entourés d'une mince chemise de sodium. Les efforts thermiques sont réduits en préchauffant l'eau d'admission à la température de saturation et en faisant circuler le métal liquide à grande vitesse pour réduire l'abaissement de température.

Flüssige Metalle als Medien für die Wärmeübertragung

Natrium und Natrium-Kaliumlegierungen werden in Bezug auf ihre Eigenschaften als Wärmeübertragungsmedien untersucht und zwar nicht nur zum Zweck der direkten Kühlung von Atomreaktoren, sondern ganz allgemein für viele industrielle Verfahren. Unter den angeführten Beispielen findet sich die Oxydierung von Naphtalin zu phthalsaurem Anhydrid, die bei einer Temperatur von ungefähr 400°C am besten vor sich geht, ferner Polymerisations-verfahren, wenn auch die Betriebstemperaturen geringer sind, und meistens mit Einzelchargen gearbeitet wird.

Da die Kosten grosser Anlagen aus rostfreiem Stahl erhablich sind, wird die Verwendung von kohlenstoffarmen Stählen in einer experimentellen Kreislaufringanlage durch die A.P.V. Co. Ltd., Crawley, Sussex, untersucht, um so die Korrosionsrate zu bestimmen.

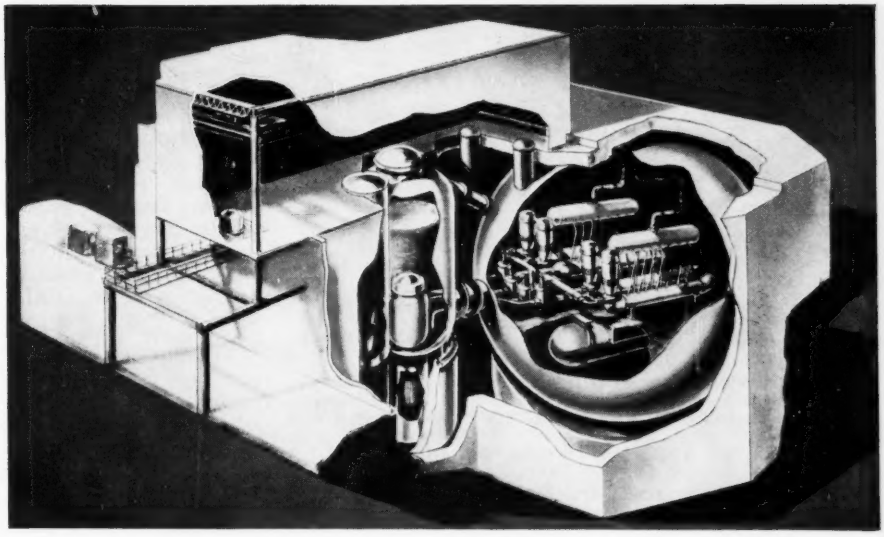
Erhebliche Ersparnisse können ferner dadurch erzielt werden, dass die Wärmeaustauscher mit einfachen Wandungen anstatt der Doppelwandungen konstruiert werden, die man in den Dounreay Natrium/Wasser Wärmeaustauschern angewendet hat. Das Bild eines Verdampfers mit entlang der einfachen Wandung abwärts fliessendem Kühlfilm wird beschrieben; der Dampf bildet sich in Druckrohren, die innerhalb einer dünnen Natriumschicht liegen. Wärmespannungen werden durch Anwärmung des Wassers auf Sättigungstemperatur vor Eintritt in den Wärmeaustauscher reduziert, ferner dadurch, dass das flüssige Metall mit grosser Geschwindigkeit zirkuliert, um den Temperaturabfall zu reduzieren.

Los metales líquidos como medios de transferencia de calor

Se viene investigando las posibilidades de las aleaciones de sodio y potasio de sodio como medio de transferencia de calor no solamente para el enfriamiento directo de reactores nucleares, sino para su empleo en muchos procedimientos industriales. Los ejemplos incluyen la oxidación de naftalina en anhidrido phtálico que tiene una temperatura óptima de operación de unos 400°C y procesos de polimerisación aunque la temperatura de operación sea más baja y por eso se emplea generalmente un sistema de "hornada" o lote.

Para reducir el costo de los grandes circuitos de acero inoxidable se viene investigando ahora el empleo de acero dulce para determinar las razones de corrosión en un lazo experimental por A.P.V. Co. Ltd., de Crawley, Sussex.

Se puede lograr una economía notable en el diseño de los intercambiadores térmicos dándoles paredes sencillas en lugar del sistema de doble pared adoptado en los intercambiadores térmicos Dounreay de "sodio-a-agua." Se ilustra un evaporizador de pared sencilla y película bajante y se hace un descripción del mismo, en el cual el vapor se forma en los tubos de presión que quedan rodeados de una delgada camisa de sodio. Los esfuerzos térmicos son reducidos por el precalentamiento del agua de entrada a temperatura de saturación y circulando el metal líquido a gran velocidad para reducir la baja de temperatura.



Artist's impression of the pressurized water reactor with oil-fired steam superheating, planned by the Consolidated Edison Co., N.Y.

First Commercial Pressurized Water Reactor

On May 4 the U.S.A.E.C. officially approved plans for the construction of a privately owned and operated reactor power station with an installed capacity of 236 MW. The station is due to go into operation some time in 1960.

THE Consolidated Edison Company of New York is planning to construct a nuclear steam electric generating station on the Hudson River about 24 miles north of New York City. The reactor will be a pressurized water, converter type and will be the first commercial unit to use thorium as the fertile material to supplement uranium-235.

The saturated steam leaving the reactor will be superheated in a separate oil-fired unit, to increase the generating capacity by 96,000 kW giving a total capacity of 236,000 kW.

Reactor Design

The reactor will be fuelled initially with highly enriched U 235, and moderated and cooled with pressurized light water. The core is planned to be a right cylinder about 6 ft. high and 6 ft. in mean diameter, made up of over 100 replaceable fuel elements. Each of the latter will be square in cross-section and contain alternate fuel and fertile plates separated by coolant channels.

The fuel plates will consist of uranium-Zircaloy, and the fertile plates of thorium, both clad with Zircaloy. Separation of the fissionable and the fertile material in this manner makes possible relatively lengthy irradiation of the fuel elements before they need be removed, and high burn-up figures are therefore expected. Thorium was chosen because of its structural properties, its compatibility with Zircaloy, low irradiation damage, and superior ability to supplement the original fuel supply.

The core will be surrounded laterally by a 6-in. water reflector and the entire assembly housed in a thick-walled pressure vessel. Steel thermal shields will protect the pressure vessel against structural damage and excessive heating from neutron and gamma flux. A portion of the main coolant flow can be diverted to cool the thermal shields and pressure vessel.

The composition of the core is determined by the requirements of heat transfer, structural integrity, excess reactivity, and the need for an adequate negative temperature coefficient. With about 70% of the core volume filled with water and an inventory of about 8,100 kg of thorium, approximately 275 kg of highly enriched U 235 provides sufficient excess fuel to accommodate the various reactivity changes. With this loading initial thermal neutron flux at full power is approximately 6.10^{13}n/cm^2-sec.

Under normal conditions, 120,000 gal./min. of coolant water will pass through the reactor, the greatest proportion flowing through the fuel element coolant channels, but a considerable quantity will be diverted for the control rods, reflector, and thermal shields. Flow is upward, and single-pass, from four inlet connections in the lower section of the pressure vessel to four outlet connections in the upper section. The coolant temperature is limited by a maximum fuel plate surface temperature of 600°F. Mean reactor water outlet temperature will be 510°F and mean reactor water inlet temperature 480°F.

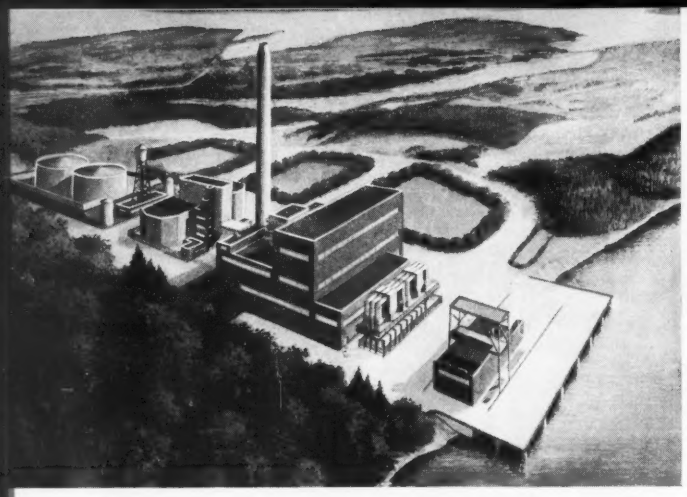
Reactivity control will be exercised by 21 individually operated cross-shaped boron steel control rods, the effective parts of which are about 5½ ft. long. The proposed pattern is a central regulating rod surrounded by 20 shim rods in two concentric rings. The size and location of the rods will provide for 5% negative δk in the cold, clean condition, and also obtain some degree of flux uniformity during operation.

Hydraulic actuators and electro-mechanical actuators with canned and external drives and buffer seals are under consideration, but final plans have not yet been made.

Reactor Pressure Vessel and Containment

The reactor pressure vessel will consist of a cylindrical shell of carbon steel about 10 ft. in diameter and about 23 ft. high. The inner face will be clad with type 304 stainless steel.

The openings in the vessel will comprise four inlet nozzles, 20½ in. I.D. located in the bottom hemispherical head; four



A general view of the station as it will appear when completed. Detailed plans of construction are not finalized but decisions have been reached on the majority of the design parameters.

outlet nozzles, of the same diameter, located in the spherical reducing section; and a top closure, which permits access to the core for removal and replacement of the fuel elements and other internal parts, which will be sealed by a double gasket arrangement pressurized with water. The vessel will be set vertically in its containment shell, a skirt-type support enabling the vessel to expand whilst held firmly in position.

The containment shell will be filled with de-mineralized water to a depth of 18 ft. above the closure head of the vessel and will provide shielding during normal operation; it will also protect personnel during fuel loading and unloading. The thermal insulation around the outside of the vessel will be sealed in a jacket of carbon steel clad on the outside with stainless steel, and the outer surface of the closure head waterproofed by a stainless-steel covering; each stud and nut will be chromium plated to prevent corrosion. Because the energy absorbed by the water shield around the reactor vessel will be considerable, it is planned to provide a heat removal system consisting of a single vertical coil of tubing carrying cooling water.

Primary Coolant System and Containment

The primary coolant system will consist essentially of four loops operating in parallel. Each loop comprises a boiler, two 15,000 gal./min. pumps with associated check valves, 24-in. stainless-steel piping, and two 24-in. remotely-operated stop valves to permit isolation of the loop. The reactor will be located low in the system, thus permitting drainage of a boiler loop without uncovering the core, whilst the pressurizer will be built high in the system, thus facilitating venting, filling and pressure control. Pressure is applied to the system by a steam head in the upper part of the pressurizer generated by cartridge type electric heaters.

The pressurizer is designed to accommodate the contraction and expansion of the primary coolant due to changes in steam demand and will be equipped with a spray nozzle connected with the reactor for additional pressure control and possible degasification; a water level control device with high and low limit indicators will be incorporated. It is planned to mount a pressure relief valve set to discharge at 1,800 psia, on the top of the vessel. Effluent from this valve will be piped to the waste-disposal system. All possible air entrapment volumes in the system will be vented and with the exception of the reactor, drain lines will be connected to any potential water trap.

Each boiler will consist of two major components; an evaporator section and a separate steam drum. The evaporator section comprises U-shaped stainless-steel tubes, the ends of which are welded into heavy tube sheets, enclosed in a U-shaped carbon-steel shell. This design eliminates the need for an expansion joint in the shell, since differential thermal expansion will be taken up in the return bend. Primary coolant flows through the tubes, steam being generated in the water surrounding the tubes and flowing up to the steam drum.

With the feedwater at 332°F, each of the four boilers will generate about 472,000 lb. of saturated steam per hour at a pressure of 420 psia under full power conditions. At heat loads less than full reactor rating, these units generate steam at a rate commensurate with the heat supplied to them and at a constant steam pressure of 420 psia. During normal reactor cooling cycles, as well as emergency cooling periods, these units will serve to remove excess heat.

During shutdown, heat will continue to be generated in the fuel elements by radioactive decay and normal shutdown procedures provide that the elements are cooled by forced circulating until they are able to be cooled by natural convection. In the event of power failure, emergency drives for one main cooling pump in each loop will supply adequate circulation during the shutdown period.

The two main coolant pumps in each of the four circuits will operate in parallel at constant speed for all reactor loads. One pump in each loop can, however, be operated at low speed from an emergency power supply. Both canned-motor and gland-sealed pumps with separate drive motors are being considered. They will be designed to operate in a vertical position.

There will be three main sources of power to the pumps; two system high lines and the plant generator. There will be three pumps on each of two sources of power and two pumps on the third source. The loss of any two sources of power would leave a minimum of two pumps operating at full speed, one in each of the two circuits. The loss of all three sources of power will activate gear to switch the four two-speed pumps to auxiliary power.

Should the gland sealed rod drives and pumps be installed, the system for maintaining primary water quality would be integrated with the buffer seal system. Some seal water bleeds continuously into the primary system through the seals. An equivalent amount of water is blown down from the primary loop to keep the water level in the pressurizer constant. According to the present estimates of seal leakage into the primary loop this blow-down will maintain the concentration of total solids in the primary loop water at a value less than 1 ppm.

For both under normal operation and decontamination after a fuel element failure, the "blow-down" water will be treated and re-used in the primary system. Any water which leaks into the containments can be drained off to the low-pressure drain tank, purified through the same system as the "blow-down" water and re-used. This results in very low make-up water requirements for the system.

The water blown down from the primary loop will be cooled to approximately 250°F in a tubular heat exchanger. The pressure of the water will then be dropped to about 30 psia in a flash tank where some of the water flashes to steam and any dissolved gases are driven off. The flashed steam is condensed in a vent condenser and returned to the blow-down flash tank.

The water from the blow-down flash tank will be cooled to 110°F in another tubular heat exchanger and sent to one of the two contaminated water storage tanks. Water from these tanks will be pumped through filters to remove insoluble corrosion products and passed through mixed-bed ion exchangers to remove soluble, ionized products. Purified water can be stored in decontaminated storage tanks and re-used as seal water. The same purification system can be used to decontaminate the primary system coolant and shield-tank water in the event of a fuel element failure.

All four boiler loops will be adequately contained in vessels designed to hold safely the vapour released through a mechanical failure of any pressure part in the coolant system. The two 70 ft. diameter spheres each contain two loops. The spherical containers are connected to the vapour space of the reactor containment shell and to each other by means of large ducts. In order to avoid the possibility of radioactive air pollution in the event of an explosion, no fresh air will be introduced into the containers. A closed circuit air-conditioning system will be provided to cool and de-humidify the residual air.

Fuel Handling

The fuel elements will consist of assemblies of 0.060 in. thick fuel plates and 0.080 in. thick fertile plates spaced alternately to provide 0.100 in. water channels. Individual plates will be about 2½ in. wide and assembled in two rows to provide a square cross-section with a lateral dimension somewhat more than two plate widths. The exact dimensions and total number of assemblies will depend upon the final specifications for control rod positions.

The assemblies will be provided with suitable top and bottom transition pieces to permit good flow distribution and facilitate firm positioning and support in the upper and lower grids. The upper grid will function as a holding down device to resit the hydraulic lifting forces on the assemblies, the lower transition piece of each assembly containing a spring mechanism to accommodate differential expansion between the elements and the core supporting structure.

Each fuel element will be shipped to and stored at the site in a hermetically-sealed metal container. A fuel element storage vault will be located above the reactor shield tank adjacent to a multi-purpose handling device. The latter will serve as a working platform for indexing the special tools over desired refuelling locations within the shield tank and provide a partial closure of the shield tank for control of shield tank ventilation while fuel handling operations are taking place. Heavy lifting will be carried out by a 25-ton service room crane.

A steel-lined concrete pit, for spent fuel storage, will be located next to the reactor shield tank, and the spent fuel elements transferred to the storage pit by an underwater chute. The water level in the storage pit during refuelling operations will be slightly lower than that in the shield tank, thus preventing contamination of shield tank water with water from the storage pit.

It is expected that normal replacement of one-third of the core could be accomplished in a total time of 36 hours.

Shielding and Maintenance

The shielding of the plant can be separated into three distinct problems: reactor and pressure vessel; primary coolant piping and boilers; and fuel removal and storage.

During full power operation the reactor will produce neutrons with energies ranging from thermal to greater than 10 MeV, and gamma rays from zero to 8 MeV. One of the most effective methods of shielding the reactor is to surround the pressure vessel with a substantial layer of water. The water layer over the reactor pressure vessel will be sufficient to reduce the gamma ray dose rate to below the m.p.l. (7.5 mr/hr.) above the containment tank during full-power operation and permit the removal of the pressure vessel head after shut-down without additional shielding.

Primary coolant water acquires short half-life oxygen and nitrogen activity in passing through the core. The primary emission is a 6-MeV gamma ray. This radiation determines the thickness and location of the primary coolant loop shield, but in view of short half-life activity, accessibility after shut-down will be no problem. The height of water in the spent fuel storage pit provides adequate shielding so that personnel may operate the necessary manipulating equipment to place the elements in storage racks or transfer them to shipping coffins.

Le premier réacteur commercial à eau pressurisée

La Consolidated Edison Company de New York a reçu l'autorisation de l'A.E.C. de construire une centrale nucléaire à environ 38 km. au Nord de New York City. Le réacteur sera du type de convertisseur d'eau pressurisée employant du thorium comme matériau fertile et sa production prévue est de 140 MW lesquelles, avec 96 MW de surchauffage par combustion d'huile, donnera une capacité installée de 200 MW.

Le noyau, de 1,83 m. de haut et de 1,83 m. de diamètre, se compose de plus de 100 éléments contenant des plaques d'uranium-alliage de zirconium alternant avec des plaques de thorium recouvertes d'alliage de zirconium. Il est monté dans un bac à pression rempli d'eau pour laisser 15 cms. de réflexion sur les côtés. Le chargement en combustible s'élève à 275 kg. d'U 235 et 8.100 kg. de thorium. Le refroidissement est par eau qui est faite circuler par quatre échangeurs de chaleur avec un débit total de 12.000 gal. (54.550 litres) par minute à plein rendement. La température maximum du combustible est de 600°F (315°C) et la température moyenne de 510°F (266°C) et 480°F (249°C) 21 barres d'acier au bore en forme de croix son employées pour le contrôle.

On y discute les détails de construction du bac à pression et du réceptacle, le système réfrigérant primaire, les éléments combustibles et la protection. La table indique les caractéristiques de vapeur et électriques principales et l'évaluation provisoire des frais.

Der erste gewerbliche Druckwasser Reaktor

Die Consolidated Edison Co., New York, hat die Genehmigung von der A.E.C. erhalten, ein Atomkraftwerk ungefähr 24 Meilen (engl.) nördlich von der Stadt New York zu bauen. Der Reaktor wird als mit Druckwasser arbeitender Reaktor gebaut, wobei Thorium als Ausgangsmaterial benutzt wird; er soll 140 MW erzeugen, was zusammen mit dem ölgefeuerten 96 MW Ueberhitzer eine Gesamtkapazität von 200 MW ergibt.

Der Kern von 6 Fuss Höhe und 6 Fuss Durchmesser wird aus über 100 Elementen zusammengesetzt, die abwechselnd aus Uranium-Zircaloy Platten und Thorium Platten mit Zircaloy bedeckt bestehen. Der Kern ist in einem mit Wasser gefüllten Hochdruckkessel montiert mit 6 Zoll Reflektorbreite an den Seiten. Die Brennstoffüllung beträgt 275 kg. U 235 und 8,100 kg. Thorium. Kühlung erfolgt mit Wasser, das durch vier Wärmeaustauscher zirkuliert bei einem Gesamtfluss von 12,000 Gallonen pro Minute unter Vollast. Maximum Brennstofftemperatur ist 600°F, mittlere Temperaturen 510°F und 480°F. 21 kreuzförmige Borstahlstangen dienen zur Kontrolle.

Einzelheiten der Konstruktion von Hochdruckkessel und -behälter, von der Hauptkühlanlage, der Brennstoffelemente und des Strahlungsschutzes werden besprochen. Eine Tabelle bringt die wesentlichen Dampf- und Elektrizitätskennzahlen und eine überschlägliche Kostenaufstellung.

El primer reactor comercial de agua presurizada

La Consolidated Edison Company de Nueva York ha sido autorizada por la A.E.C. para construir una central de fuerza nuclear a unos 38 km. aproximadamente de la ciudad de Nueva York. El reactor será del tipo convertidor de agua a presión, empleando el torio como material fértil y está calculado para generar 140 MW, los cuales, juntamente con 96 MW de recalentamiento alimentado con petróleo, dará una capacidad instalada de 200 MW.

El núcleo de 1,83 m. de altura y 1,83 m. de diámetro, está formado por más de 100 elementos conteniendo placas alternativas de uranio-aleación de zirconio con placas de torio revestidas de aleación de zirconio. Esto va montado en un recipiente de presión lleno de agua, dejando 15 cm. de reflexión a los costados. La carga de combustible representa 275 kg. de U 235 y 8.100 kg. de torio. El enfriamiento se hace por circulación de agua a través de cuatro intercambiadores térmicos con un flujo total de 12.000 galones (54.550 litros) por minuto a pleno rendimiento. La temperatura máxima del combustible es de 600°F (315°C) y la temperatura media de 510°F (266°C) y 480°F (249°C). Para el control se emplean 21 barras de acero al boro en forma de cruz.

Se discuten los detalles de construcción del envase a presión y del recipiente, el sistema primario de refrigeración, los elementos de combustión y la envoltura protectora. La tabla muestra las características principales de vapor y electricidad, y el cálculo provisional de costo.

Superheating

Since present temperature limitations of reactors result in saturated steam of relatively low pressure and therefore temperature as compared with modern steam plants, the company decided to investigate the economics of superheating the steam generated by the reactor before using it in the turbo-generator. The cost, capacity and heating rate, exclusive of reactor thermal efficiency, were calculated for a plant using the saturated steam produced by the reactor to run the turbine, and for an alternative plant in which the saturated steam from the reactor would be superheated in a separate oil-fired superheater. The results of the study which contains certain optimistic assumptions concerning capital cost and burn-up are given in Table 1. They indicate that superheating results in an increase in capacity from 140,000 kW to 236,000 kW and a reduction in cost from $322 per kW for a plant using only nuclear fuel to an average cost of $233 per kW for a combination of a nuclear boiler and a separate oil-fired superheater. By comparison, the cost of building conventional generating equipment in New York City is $250 per kW. The use of superheat will also reduce the maintenance costs on the turbine as compared with a unit operating on wet steam throughout.

If the relative costs of nuclear plants are reduced sufficiently in the future, or the cost of nuclear fuel as compared with the cost of conventional fuels reduced, or if superheating with the reactor to high steam temperatures of about 1,000°F becomes possible, then superheating by means of a separate superheater using conventional fuels would be uneconomic.

TABLE 1. Estimated Costs and Capacities

	Case I Saturated steam	*Case II Superheated steam*
Steam pressure at boiler, psia ...	420	420
Steam pressure, turbine inlet, psia	405	370
Steam temperatures, turbine inlet, °F	446	1,000
Gross electrical output, kW ...	140,000	236,000
Turbine plant heat rate, BTU/kWh	12,900	10,700
Total cost of plant	$45,000,000	$55,000,000
Total plant cost per kW	$322	$233

Operating Features

The reactor will be regulated to provide constant steam pressure in the boiler regardless of the load on the turbo-generator. This avoids the use of a main line pressure-reducing valve which would otherwise be necessary if the reactor were controlled for constant reactor temperature. The reactor will also be designed so that load may be increased from 15 to 100% in half an hour and so that the load may be taken off the unit at the same rate. Operation below 15% of full load is not contemplated because of reactor limitations. If the turbo-generator trips out or is taken out of service for minor reasons and it is expected that the unit will be restored in a few hours, the reactor will be kept in operating condition and loaded to 15% of capacity by means of a steam by-pass around the main turbo-generator. By using a pressure reducing valve and de-superheater in the by-pass, steam will be passed directly to the condenser and the heat rejected to the river.

Bremsstrahlung Thickness Gauge

ONE of the major objections to the use of γ-gauges in the steel-rolling industry, for coverage of the thickness range 0.050 to 0.500 in., is the short half life associated with emitters of appropriate energy. The most useful radio-isotope is thulium-170 with a 3% emission of 0.084 MeV and 5% emmission of 0.053 MeV. The half life, however, is 129 days, which necessitates source changing at aproximately six-monthly intervals. An alternative source is beta-ray-generated Bremsstrahlung. A suitable radio-isotope is strontium-90 in association with its decay product, yttrium-90, giving a maximum beta-ray energy of 2.18 MeV with a half life of 19.9 years.

Main electronics cabinet and head unit for the Baldwin prototype Bremsstrahlung gauge. This instrument is designed to use a long life β-emitter as a source of electro-magnetic radiation for thickness determinations of hot rolled strip.

In collaboration with the Radio Chemical Centre, Amersham, Baldwin Instrument Co. Ltd., of Dartford, have developed a Bremsstrahlung source and this, with a detector unit, is being used for the non-contact measurement of hot-rolled strip. The prototype unit is at present under test at a steelworks in Sheffield.

The detector head comprises a scintillation counter of conventional design. During the interval between individual coils a system of automatic standardization is brought into action to eliminate errors caused by changes in sensitivity of the head unit and drifts in the electronics. At a thickness of 0.1 in. steel, present estimates place the standard at deviation $\pm$ 0.5% with the time constant set to a figure of 1 second.

When proved, the instrument is expected to have a considerable market in the metal-rolling industry where existing X-ray gauges are both costly and difficult to maintain. The advantages of a sealed source of radiation with a constant rate of emission are considerable, and whilst the organization required for a regular change of gamma source is not formidable the less maintenance effort required the better. Furthermore, the repetitive handling of multicurie thulium sources is not an easy task. Some concern may be expressed at the use of small, very high activity, strontium sources in installations where violent mechanical damage is not unknown, and the initial deposition must therefore be carefully controlled so that should the source container be damaged there is no possibility of distributing the strontium in an assimilable form.

Design Aspects of Radiation Instruments

by
E. N. SHAW, B.Sc.

Radio-isotopes are still only little used in production control processes. One of the major problems to be overcome is advising the production engineer on the potentialities and also the limitations of radiation instruments. Continuous and switch operation are discussed in terms of accuracy and speed of response.

IMPROVEMENTS in detection equipment and operational techniques are increasing the scope of radio-isotopes in production control. Applications of these techniques however are not widespread and their expansion will largely depend upon the appreciation of the production engineers of the advantages and limitations involved. Whilst in some instances there is a tendency to use radio-isotopes when existing instruments already fulfil the necessary qualifications there is more frequently a tendency to mistrust new techniques. Failure to appreciate some of the inherent characteristics of radiation instruments creates a false impression of their potentialities.

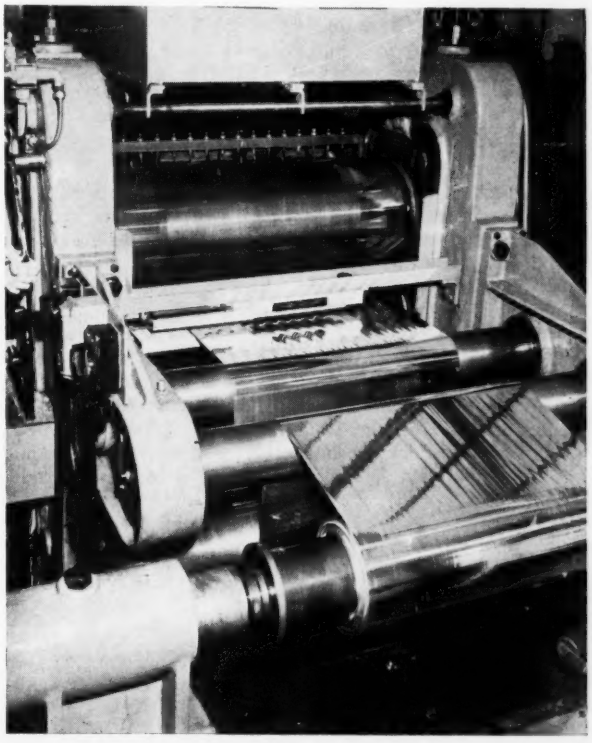
The unfamiliar aspects fall into two main categories. The first is the source—emitting unseen radiations in an irregular and uncontrollable manner and the second is the detection gear largely composed of electronics, a subject which is still not generally accepted as a normal part of the maintenance engineer's training, although this position is steadily changing. Without some knowledge of the processes involved in each category the control engineer is liable firstly to set an unreasonable specification for the performance of the instrument and then to be dissatisfied with the results even when the specification is fulfilled.

This specification, although admittedly chiefly the responsibility of the production engineer who will base his requirements on the needs of the process machine, must be drawn up in consultation with the designer to avoid unnecessary complexity and even mutually incompatible conditions. Main features will concern accuracy, stability and speed of response and although one of these may be inherently defined in the function of the process machine some compromise can usually be made between the ideal and the practicable and economic.

Whereas with many industrial instruments accuracy can be simply stated in terms of outside limits beyond which the output indication should never stray, the same is not true with a radiation gauge where the errors involved require to be stated in terms of a probability of occurrence. The magnitude of the probability that is permissible will vary considerably with each individual problem and the figure finally approved in the specification must be a realistic measure of the importance of the error when related to the process machine's functions, tolerances on output and ability to correct genuine divergences from the ideal.

Stability problems are in general no more serious than those normally encountered in mechanical and electrical engineering, except that, superimposed on any drifts will be the random fluctuations in the source emission which may require a more careful analysis of the overall effects. Achievement of electronic stability should only present unusual difficulties where the techniques employed are peculiar to radiation detectors. Both ionization chambers and scintillation counters have introduced into factories current magnitudes and pulse circuits which until recently were confined to the laboratories. Automatic standardization is normally possible provided that the additional complication and expense can be justified.

Unfortunately few production engineers are familiar with the conception of a time constant—invariably an inescapable feature of a radiation instrument. Normal machinery has conditioned the engineer to (effective) instantaneous operation, constant and variable delays and networks that rely on time derivatives of distance, but the exponential type of response is as yet rarely met on the factory floor. Furthermore the accuracy and time constant are interrelated through the source strength and source counter geometry. In drawing up a specification the aim should always be to keep the source strength to a minimum and the immediate result of this is that the time constant should be as long as is compatible with the useful functioning of the instrument. With improvement in source deposition and encapsulation techniques the designer is now less restricted but an increase in source strength inevitably implies greater care in the



A transmission beta-gauge manufactured by Baldwin Instrument Co. Ltd., of Dartford, installed on a metal rolling mill.

shielding design and greater expense in production; on general principles it is desirable to limit the amount of radioactivity in a particular installation.

Two distinct types of radiation instrument are in current use, the direct reading instrument as typified by the beta gauge where a continuous output is required, monitoring the thickness of a rolled strip and the radiation switch which is required to give a periodic "yes-no" answer.

Beta Gauges

Beta gauges consist essentially of a source mounted remote from the strip with a detector mounted either on the far side (transmission gauge) or on the same side screened from the direct radiation (reflection gauge). The response of the detector in the two cases is illustrated in Fig. 1. Only the transmission gauge will be considered in detail as the arguments are applicable to most continuous indicating radiation instruments. The detector is comprised of an ionization chamber or scintillation counter and the standing current is either backed off at the input to the amplifying network by an equal and opposite supply or in the amplifier itself by a suitable controllable current or voltage source. The main output will be observable on an "off-gauge" meter although provision for a recorder, limit switches or automatic thickness control can be made. The response of this meter to a sudden change in thickness is shown in Fig. 2.

Before the main features of a suitable instrument for monitoring thickness can be settled the designer requires to know:

1. Range of thickness (or better weight/unit area) covered.
2. Accuracy in terms of standard deviation of the output and long term stability.
3. Response time expressed as a time constant.
4. Mechanical considerations affecting the disposition of source and detector relative to the strip.

For the purposes of discussion the production machine is assumed to be a rolling mill, rolling steel to a finished thickness of 0.005 in. to 0.045 in., at a speed of 1,000 ft./min.

At the outset is should be appreciated that whilst it is desirable that the instrument should be in use during 100% of production if coverage for a small fraction of the complete range increases the complexity of the instrument considerably or unduly steps up the source strength or decreases the efficiency over the main part of the range some compromise should probably be effected.

Starting points for determining the accuracy necessary, are the tolerances required (or anticipated) on the production material and the ability of the machine to produce a uniform product if fed with the correct information. Rarely is the first consideration overriding and other factors affecting the saving of raw material are likely to be paramount. This brings the question back to the efficiency of the production machine, and the uniformity of the raw material. With an instrument measuring weight/unit area constancy of density is of prime importance if uniform thickness is desired. In many industries in the United Kingdom production control is in terms of thickness but buying and selling is negotiated in terms of weight. The logical solution is to change production control methods to cater for weight measurements but the hand micrometer is still regrettably the standard checking instrument. It is also common for different parts of a factory to think in terms of percentage tolerances and absolute tolerances and this may have a significant bearing on the specification if a large range is under review. It is probable, however, that the increasing tendency in the U.S. to think in percentages will be reflected in the U.K.

In this example it will be assumed that changes can be discussed in percentages but that a uniform thickness is the requirement from the machine. Density variations will be taken as 3%, regular variations in the thickness due to eccentricities in the rolls, etc., as 2% and discontinuities in thickness due for example to non-uniform heat treatment which are contrary to the general trend in thickness change as ± 2%. Discrepancies in the measurement of ± 1% will then be relatively small and but for the statistical fluctuations on the output this could immediately be chosen as an adequate (although not necessarily maximum) tolerance on the indicator. It is not proposed to discuss item 4—mechanical considerations in relation to the constancy of presentation of the strip to the gauge although in practice in spite of suitable collimation of source and detector minimizing the effect of strip position, irregularities in the thickness of oil film, the density of the water mist in the gap and expansion of the supporting yoke, etc., may introduce errors in excess of those mentioned. These are not however fundamental to the rolling process, and steps can be taken to reduce their effect.

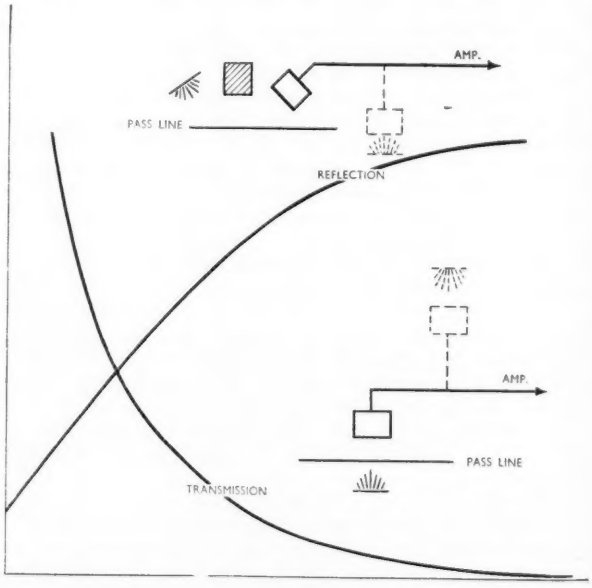


Fig. 1. Typical response curves for transmission and reflection radiation gauges. Detector current in the first case decreases nearly logarithmically with thickness and in the second initially increases linearly with thickness.

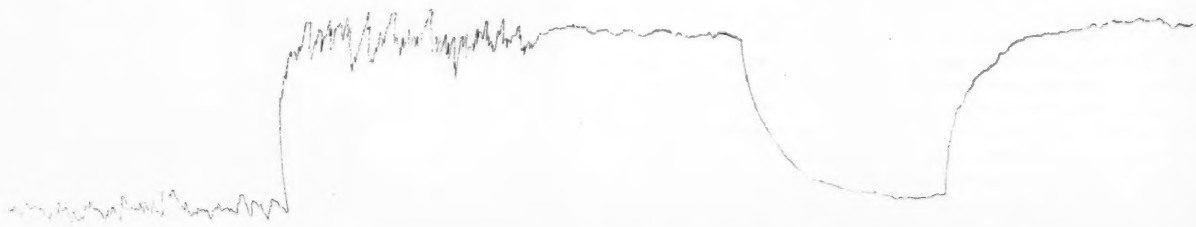


Fig. 2. Typical output from a radiation gauge showing two step function changes in material thicknesses. The count rate in the two cases is the same but the time constant changes by a factor of 100.

The major difficulty to overcome is the relating of the acceptable tolerance to the standard deviation of the output. In *Nuclear Engineering*, July (p. 152), the significance of the standard deviation was discussed in terms of the probability of a single observation being wrong and it could be inferred that the occurrence of an error amounting to five or six times the standard deviation was sufficiently remote to be considered "never." A standard deviation then on the indicator amounting to 0.1% of the rolling weight would amply fulfil the production engineer's qualification but would necessitate the use of a source strength grossly in excess of the absolute minimum. The tolerable figure will be a function of the use that is made of the information presented and the ability of the correction mechanisms to respond to small changes in setting. With manual operation the operator will be on the watch for general trends and very little experience will allow him to judge the significance of off-gauge readings once the initial distrust of a permanently "live" indicator even on static samples has been overcome. To avoid, however, a psychological analysis of his reactions an analogy can be drawn to an automatic control system which responds when the off-gauge reading exceeds a predetermined figure for a predetermined length of time and then feeds either a constant signal into the screw-down controls or a signal that is a function of the off-gauge signal with or without rate of change adjustment. Automatic control by radiation gauges is in the process of development by a number of companies and it is probable that a "bang-bang" type of process control will be adopted in most instances.

From the preceding assumptions it can be deduced that no compensation will be initiated by off-gauge readings of less than $\pm$ 2% and not until a prolonged change of 2½% is observed will steps be taken to modify the screw-down settings. The term prolonged must relate to the time taken for a given adjustment to take effect and from this figure and from the normal time/thickness curve associated with the rolling process the response time of the instrument must be calculated. Too often the time constant is based on the speed of the strip, which is misleading, as no matter what length of strip has passed through during a time constant period the important criterion is solely the time necessary to effect a change in the rolling conditions. Although several time constant intervals must have passed after a step function change in thickness before a stable reading is indicated some change is indicated immediately and the rate of change (in terms of thickness per second) is proportional to the magnitude of the step function.

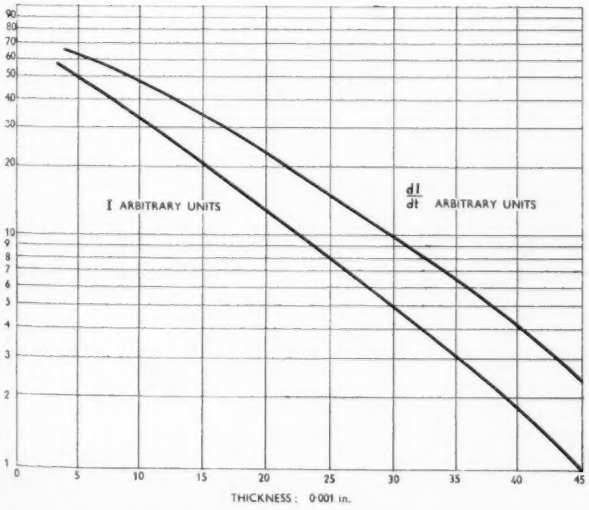


Fig. 3. Absorption and sensitivity curves for steel using a Ru 106 source. Both curves are nearly logarithmic in shape.

Differentiation between "genuine" and "statistical" changes in reading can only be made by observation of the magnitude and time of duration and the significance of a particular standard deviation must therefore be expressed in terms of the time constant. For a given source strength and detection geometry an increase in time constant causes a decrease in standard deviation and vice-versa the product of (standard deviation) and $\sqrt{}$(time constant) being a constant. It is this product ($\sigma\sqrt{\tau}$) that the designer will eventually require to know. Different automatic controls (and operators) may prefer different speeds of response but for a particular process machine $\sigma\sqrt{\tau}$ will vary little, and as a guiding principle can be made equal to one tenth of the product of the normal uncorrectable errors and the time delay associated with the correction. In the example considered a minimum time delay for a signal to be observed, translated into a signal to the screw-downs and the thickness to be changed is about 3 seconds. Accumulated errors can be taken as not less than 3% which gives a figure for $\sigma\sqrt{\tau}$ of approximately 1% sec.[1] Provision however must be made for some drifts in sensitivity and a useful method of allowing for this is to subtract from the machine errors in the above calculation, a figure of three times the accumulated instrument (excluding statistical) errors. This factor of three is generous as it implies that if drift errors between successive recalibrations exceed one-third of the machine errors the instrument cannot be designed. This is clearly a controversial issue but is nevertheless a useful guiding principle. Previous experience will allow the designer to set a value on this drift—and to specify appropriate recalibration intervals in order that it should not be exceeded; ½%/shift will be taken as a reasonable working figure. Accumulated errors are thus reduced by a factor of two and $\sigma\sqrt{\tau}$ reduces to approximately 0.5% sec.[1]

Mechanical considerations affecting the siting of source and chamber will only be discussed in so far as they affect calculations of source strength. Beta gauges require the minimum thickness of protective covering over source and chamber and for mechanical safety reasons a large gap is desirable. With increasing distance, however, source strength must increase according to a power law where the exponent at the usual distance involved is of the order of 1.6. Finite size of source and detector modifies the inverse square law. Furthermore, not only must the strength increase but the proportion of stray radiations also increases and biological shielding may become a problem. A compromise distance of 5 cm. will be taken.

The remaining problem concerns the relating of the incident radiation on the detector to thickness. Fig. 3 is an absorption curve for steel using a Ru_{106}-Rh_{106} source and ionization chamber in a geometry similar to that which would be used in practice. Superimposed is a derivative function showing the change in ionization current for a constant change in thickness. Fig. 4 re-expresses these curves to show the percentage change in ionization current for a constant percentage change in weight and the percentage change in ionization current for a constant percentage change in weight. Fig. 5 shows the change in relative standard deviation of the thickness indication (σ_t/t) over the range and is a plot of:

$$\frac{\sqrt{I}}{t} \times \frac{dt}{dI}$$

$$\text{as } \sigma_t \propto \sqrt{I\tau}\ \frac{dt}{dI}$$

An examination of the curves shows that from a statistical point of view the source strength must be calculated for the minimum thickness where σ_t/t is a maximum. In paren-

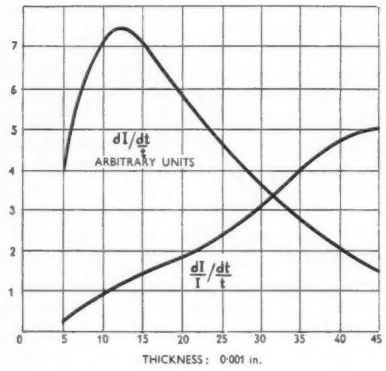


Fig. 4. Derived curves of absolute and relative current changes in the detector unit for constant percentage changes in thickness.

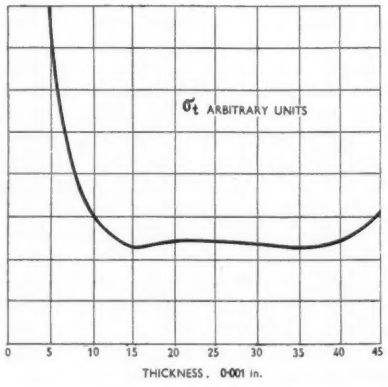


Fig. 5. Curve showing the relative significance of statistical fluctuations over the thickness range. Complex shape is caused by the departures from truly logarithmic absorption and by significant window thicknesses etc.

thesis, it should be noted that stability conditions involving proportionate current drifts are most important at the thin end of the range whereas zero drifts, i.e., absolute current drifts, are most significant at the thick end. Amplifier gain for a constant percentage sensitivity decreases to a minimum near the thin end.

Main criteria in the design can be summarized as follows:

1. Accuracy and time constant considerations lead to a figure for $\sigma_t\sqrt{\tau}$ of 0.5% sec.$^{\frac{1}{2}}$
2. Source-chamber spacing: 5 cm.
3. Minimum thickness: 0.005 in.

Efficiency of detection is assumed to be 100% so that n, the number of particles entering the chamber per second, can be calculated. If N be number of particles entering the chamber in the effective counting time so that $N=n\tau$

$$\text{we have } \sigma_t\sqrt{\tau} = 0.5\% \text{ sec.}^{\frac{1}{2}}$$

$$\text{i.e. } \sigma_t\sqrt{\tau/t} = 5.10^{-3} \text{ sec.}^{\frac{1}{2}}$$

$$\frac{\sigma_N}{N} = \frac{\sigma_t}{t}\frac{dI/I}{dt/t}$$

$$\text{if } I \propto N$$

in the worst condition therefore

$$\frac{\sigma_N}{N}\sqrt{\tau} = 5.10^{-3}.\ 0.33 \text{ (from Fig. 4)}$$

$$\text{and } \frac{\sigma_N}{N} = \frac{1}{\sqrt{N}} = \frac{1}{\sqrt{(n\tau)}}$$

$$\frac{1}{\sqrt{n}} = 1.7.\ 10^{-3}$$

$$\text{giving } n = 3.6.10^5$$

In practice I is not a simple function of n as the path lengths of the particles inside the chamber are not equal. At worst, however, the current can be considered as generated by half the particles entering and n on this account must therefore be doubled to give the necessary figure for $\sigma_t\sqrt{\tau}$.

With beta gauges which use a similar ionization chamber for backing off purposes the standard deviation of the difference current will be $\sqrt{2}$ times that of a single chamber and therefore n must again be doubled giving a final answer in round figures of

$$n = 14.10^5 \text{ particles/sec.}$$

Assuming a chamber window area of 5 cm^2

$$\text{Source strength} = \frac{14.10^5\ 4\pi 5^{1\cdot6}\ .2}{3.7.10^7\ .5} \text{ m.cc.}$$

where self absorption in source and absorption in windows and strip is taken as 2.

$$\text{Strength} = 3 \text{ mc.}$$

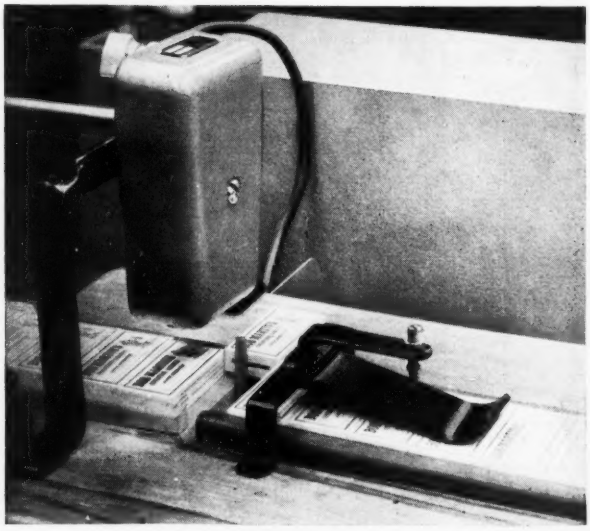
Toward the end of this calculation a number of estimations have been made, but provided that the important criteria concerning accuracy and time constant can be agreed—and understood—between production engineer and designer the method allows the essential features of a prototype to be derived.

Radiation Switch

In general there are fewer grounds for controversy in the design of a radiation switch—defined as an instrument required to give a firm decision when the radiation level at the detector has changed by a predetermined figure.

The essential decision that must be made concerns the probability of the instrument being wrong. A typical example of this is a package monitor checking the accuracy of filling of cartons as they leave the production line. From a sales point of view it is vital that no packet should be underfilled and only rarely is it economic to consider packets that are overfilled. The instrument is required therefore to reject effectively all underfilled cartons and to reject only a small number of correctly full cartons. The designer will no doubt meet with a certain lack of appreciation of the impossibility of designing an instrument which is theoretically 100% right on all occasions and where the cartons are of such a nature that the incident radiation has not simply two mean values but covers a range, a detailed examination must be made of the probability of rejection at intermediate values.

To begin with it will be assumed that the radiation level in the detector (comprising the total number of particles detected in the integrating time) changes by a factor α from



Radiation switch-package monitor manufactured by Isotope Developments Ltd., Beenham Grange, Berks, operating on an automatic carton filling machine.

N to αN, from a good to a bad sample. It is required to calculate the minimum value of N and the optimum setting of the triggering level T, Fig. 6. The count rate change τ will be a function of the radiation energy used and the absorption characteristics of the carton, and may vary in different applications from a few percent greater than unity to several orders of magnitude.

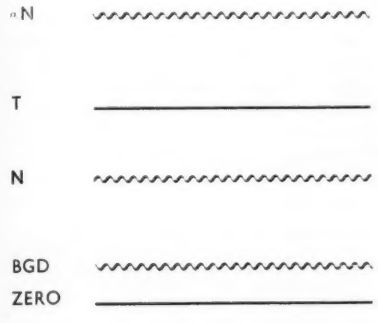


Fig. 6. Levels corresponding to response of detector to background, a full and incorrectly filled carton and the setting of the reject circuit.

If the triggering level differs from the radiation level by $3\frac{1}{2}$ times the standard deviation the chance of a wrong signal is 1 in 2,000. If the difference is 7σ the chance is 1 in 4.10^{11} and can be considered zero.

It will be assumed, therefore, that one rejected good carton in 2,000 is reasonable and therefore

$$T-N = 3.5\,\sigma_N = 3.5\,\sqrt{N}$$

whilst $\alpha N-T = 7\sqrt{\alpha N}$

solving for N and for T

$$N = \left(\frac{3.5 + 7\sqrt{\alpha}}{\alpha-1}\right)^2$$

and $T = N + 3.5\,\sqrt{N}$

If $\alpha = 2$

then $N = 180$ particles

and $T = 227$ particles equivalent

whereas if $\alpha = 1.2$

$N = 3120$

and $T = 3315$

To demonstrate the effect of a smoothly variable signal three intermediate valves will be considered, viz. when the radiation level $N_1 = T$, $N + (T-N)/2$ and $T + (\alpha N-T)/2$.

In the first case clearly there is an equal chance of the reject circuit being actuated and not actuated if the radiation level is sufficiently high for the error curve to be symmetrical about the mean.

$$\text{when } N_1 = N+(T-N)/2$$

$$\text{standard deviation} = \sqrt{N+(T-N)/2}$$

$$= \sqrt{N+3.5\,\sqrt{N}}$$

$$\text{and } T-N_1 = (T-N)/2$$

$$= 3.5\,\sqrt{N}$$

Taking the first numerical example

$T-N = 1.6$ (standard deviation)

i.e. There is a chance of 1 in 8 of the carton being rejected

when $N_1 = T + (\alpha N-T)/2$ in the same example

standard deviation $= \sqrt{22 + 67} = 17.2$

and $N_1-T = 67$

so that $N_1-T = 3.9$ (standard deviation)

and there is thus a chance of 1 in 10,000 of the carton being accepted.

Other switch problems will answer to this method of approach and the conversion of N into source strength will follow similar lines to those mentioned in the section on beta gauges. In applications where the presence of an object only requires to be detected the lower level becomes background. A further complication arises with a moving source in choosing the appropriate time constant of the detector circuit. This should be made equal to half the counting time interval calculated to give the maximum ratio of total detected count to background. If an unshielded source is moving along a straight line at a constant velocity the shape of the count/time curve can readily be calculated and the optimum time constant and the minimum source required derived. In practice however self shielding of the source and extraneous shielding of the counter require prior experimentation followed by a graphical solution.

Les aspects de la construction des instruments de radiation

Un des problèmes auxquels les fabricants d'appareillage industriel employant des radio-isotopes doivent faire face est l'inculcation à l'ingénieur de production d'une appréciation des caractéristiques de base des instruments de radiation. Les genres de discussions qui peuvent se présenter y sont discutés en se référant particulièrement à une jauge devant être montée sur un laminoir d'acier. On y exprime la suggestion que les deux considérations principales de précision et de constante de temps peuvent être dérivées en termes de l'expression τ/r; dans l'exemple donné un chiffre raisonnable est obtenu pour cette expression en tenant compte du temps de réponse des cylindres du laminoir et des erreurs inhérentes du procédé de laminage. En se basant sur ces chiffres, on dérive la valeur minimum de force de source. En contra-distinction à ce type d'application où il est besoin d'une mesure continue, l'interrupteur à irradiation est de nouveau examiné du point de vue de la conception en vue de convenir à une spécification qui tient compte des réalités et pour dériver un système qui implique une force de source minimum. Les calculs appropriés couvrant les statistiques de tels systèmes sont suivis.

Verschiedene Punkte für den Entwurf von Strahlungsinstrumenten

Eines der Probleme, die den Fabrikanten von industriellen Apparaturen, die mit Radio-Isotopen arbeiten, sehr beschäftigen, ist die Erziehung des Betriebsingenieurs zum Verständnis der grundlegenden Eigenschaften von Strahlungsmessinstrumenten. Es werden die Fragen besprochen, die am ehesten auftreten; dabei wird besonders auf eine Messeinrichtung für ein Stahlwalzwerk Bezug genommen. Es wird vorgeschlagen, die beiden Hauptpunkte, Genauigkeit und Zeitkonstante, in einer Gleichung durch eine Funkion auszudrücken, die die Form $\tau\sqrt{r}$ hat. In dem Beispiel, das angeführt wird, erhält man brauchbare Zahlen, wobei auch die Reaktionszeit für die Walzen und die dem Walzverfahren eigenen Ungenauigkeiten in Rechnung gezogen werden. Auf Grund dieser Zahlen kommt man zu einem Mindestwert für die Stärke der Strahlungsquelle. Im Gegensatz zu dieser Art der Anwendung, bei der fortlaufende Messung verlangt wird, wird ein Strahlungsschalter besprochen, bei dem es sich darum handelt, ihn so zu konstruieren, dass er allgemeinen Bedingungen genügt, wobei ein System gezeigt wird, das mit einem Minimum von Strahlung auskommt. Die Berechnungen, die die statistischen Unterlagen eines solchen Systems erfassen, werden ebenfalls gebracht.

Aspectos del diseño de instrumentos de radiación

Uno de los problemas con que se ven confrontados los fabricantes de equipo industrial en el que se utilizan los radio-isótopos es el de instruir al ingeniero de producción en el justo aprecio de las características básicas de los instrumentos de radiación. Se discuten aquí los diferentes puntos que pudieran surgir, con referencia especial a un indicador a ser instalado en una laminadora de acero. Se sugiere que los dos puntos principales: exactitud y constante de tiempo pueden ser derivados de la expresión $\tau\sqrt{r}$; en el ejemplo citado se obtiene una cifra razonable tomando en cuenta el tiempo de respuesta de los rodillos de la laminadora y las in inexactitudes inherentes de todo procedimiento de laminado. Basándose en estas cifras se obtiene el valor mínimo para fuerza de origen. En contraposición a este tipo de aplicación en el que se requiere una medición contínua se discute de nuevo el interruptor de irradiación, desde el punto de vista de diseño para completar una especificación realista y lograr un sistema que signifique una fuerza mínima de origen. Se siguen los cálculos apropriados que cubren las estadísticas en tales sistemas.

A Versatile Van de Graaff

Flexible Operation a Feature of New S.T.L. Unit

RADIATION of five different types is available from a Van de Graaff machine recently installed at the Enfield establishment of Standard Telecommunication Laboratories Ltd., an associate of Standard Telephones and Cables Ltd. Manufactured by the High Voltage Engineering Corporation of Cambridge (Mass.) the unit is designed to produce beams of electrons, protons, deuterons, neutrons, or high-speed X-rays, as required.

Building

The new two-storey laboratory to house the machine has been constructed of reinforced concrete, the outer walls being stepped from 1 ft. thick for the upper storey to 3 ft. thick at the lowest part, providing adequate biological shielding. The machine, with its associated vacuum pumps and cold trap, is housed in the upper storey, the target

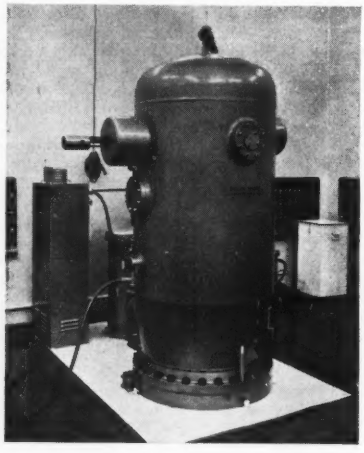


Fig. 1. Accelerator in upper laboratory.

room being located immediately below. Control gear and auxiliary equipment is also housed on the ground floor, the control console adjoining the target room, but separated from it by a labyrinth passage.

Machine—Upper Portion

The machine follows the normal Van de Graaff constructional principles, the charge-collecting belt being composed of a mixture of cotton and neoprene, running at a speed of 4,000 ft./min. The initial charge, provided by a valve rectifier equipment, is at 35 kV, and the normal operating voltage of the machine is 2 MV with a steady beam power of 500 W. The shielding rings in the main insulator column have their potentials stabilized by a resistor network totalling 93,000

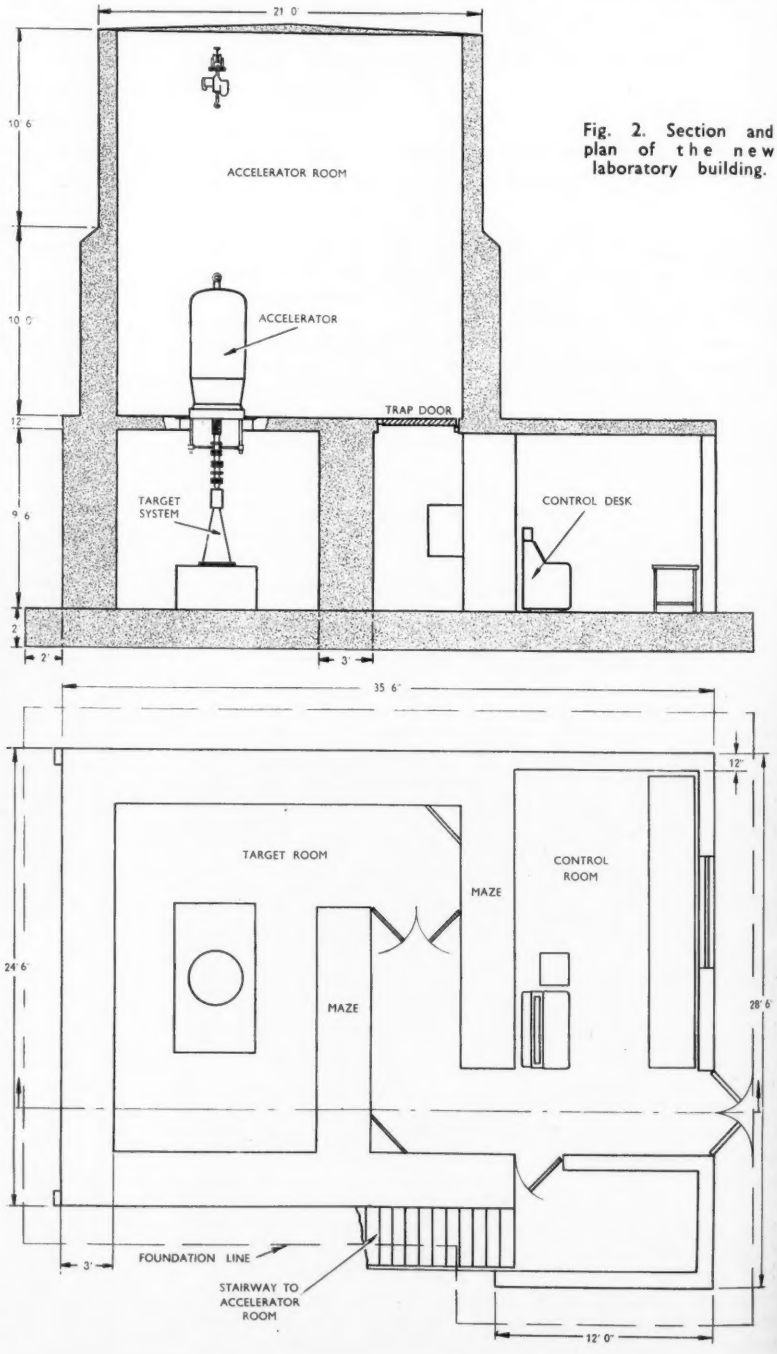


Fig. 2. Section and plan of the new laboratory building.

MΩ located inside the column; the leakage current through this network is led through a microammeter which is calibrated in terms of the operating voltage.

The machine is pressurized to 380 p.s.i. with nitrogen having an admixture of 20% CO_2. One of the minor refinements incorporated is the ability to reduce the working voltage to one-half of normal, when this is indicated for certain work. A gland on the side of the machine enables a steel "prod" or spike to be inserted which short-circuits half the resistance network. Seals located within the gland enable this to be carried out under pressure.

Variations in the type of radiation emitted are accomplished by changing the gun assembly. The electron gun has, of course, the normal type of hot filament. An ion gun is also available for proton emission (the polarity of the machine being reversible for this purpose) or for deuterons. The necessary deuterium for this purpose is obtained by the electrolysis of heavy water, a separate apparatus for this being located on the ground floor. Neutrons are obtained by bombardment of a beryllium target; this is contained at the centre of a block of paraffin wax about 1 yd^3 to act as a moderator for high-speed neutrons and reduce them to thermal velocities. Substitution of a gold target gives high-speed X-rays.

The upper laboratory also houses part of the vacuum equipment for the main accelerating tube. A refrigerated cold trap is provided to condense any organic vapours from the tube seals, and prevent them entering the diffusion pump system.

The upper laboratory has a liberal amount of free space and adequate cupboard-top accommodation to facilitate dismantling the machine for gun changing and overhaul work so that parts may be laid out in an orderly manner, under clean conditions.

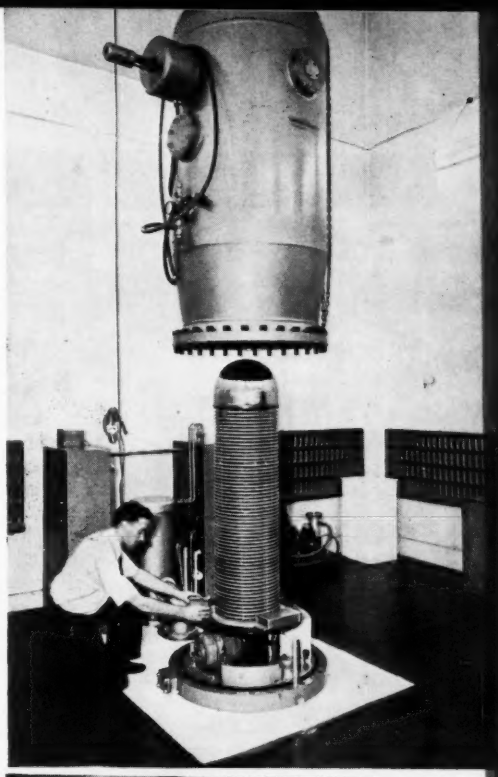
Machine—Target End

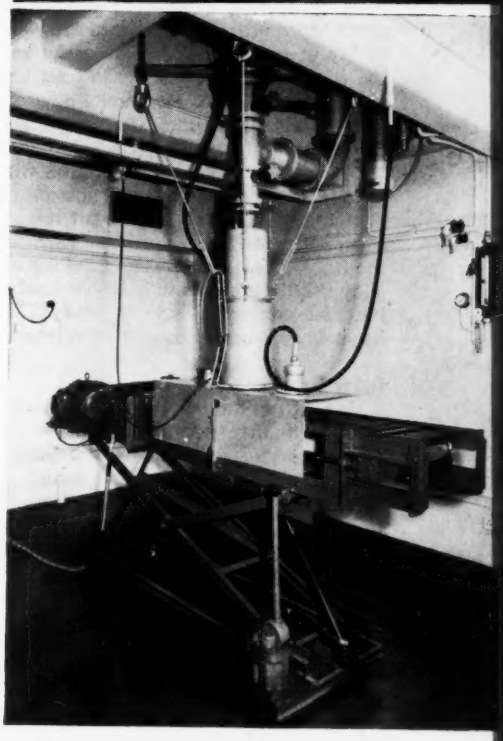
The arrangement of the target room is shown in Fig. 4, which shows the lower end of the accelerating tube. Specimens for irradiation are carried on the conveyor which is provided with a variable-speed automatic reversal arrangement. The entire conveyor unit may be raised and lowered by hydraulic jacks.

Outside the target room is the main control console (Fig. 5) carrying instrumentation and control gear for the complete equipment, including the magnetic focusing of the beam which can be accurately focused down to a spot of only 40 mils dia. A series of mirrors located in the target room and labyrinth enables the operator to get a good view of the surface of the specimen while actually under the beam, by means of a telescope attached to the control console.

The stringent safety precautions include comprehensive electrical interlocks, and a powerful blower system assures adequate ventilation and the immediate dispersal of the ozone formed by ionization during operation of the unit.

It is expected that the new machine will prove of considerable assistance in the production of short-lived isotopes, but it is anticipated that its major work will be on solid state research, and semi-conductors. The irradiation of dielectrics will, it is also felt, provide some interesting possibilities.





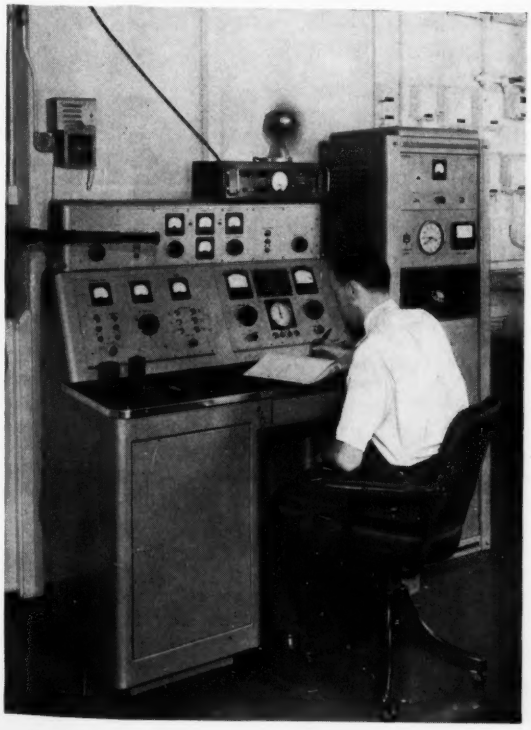


Fig. 3. (top right) Accelerator unit with pressure shell removed.

Fig. 4. (lower right) Target room showing conveyor unit for carrying specimens under the beam.

Fig. 5. (left) Control console (note telescope at the left of the operator).

High-Vacuum Metallurgy

Growing Importance in the Nuclear Field

A SHORT paragraph in the August issue of *Nuclear Engineering* briefly recorded the formation of a new company* but gave little indication of the bearing that this fusion of interests may have upon metallurgical techniques in general and, consequently, upon our own industry. The idea of melting metals in a vacuum is by no means new: the extension of this idea to the realms of really high vacua, and its translation into an industrial process, however, is. The modern vacuum furnace, capable of maintaining a high vacuum and of operating on a production basis, presents the metallurgist with a powerful tool which may clear up many difficulties of long standing.

The original conception of vacuum melting was, and still is, of course, the melting of metals without contact with oxygen, and the removal of occluded gases. Vacua at first were fairly coarse and the process of the pre-war years could more properly be termed "low-pressure" melting. The ability to produce high vacua easily and the development of the actual mechanics of the melting process have both been necessary to achieve the results now obtained.

These results indicate that, in general, the vacuum melted product has, due to the removal of the dissolved gases and the inclusions inevitably associated with an air-melted product, a greater density and superior mechanical properties. Furthermore it enables consistent results to be obtained from every melt, this being, perhaps, its most valuable advantage. It is not claimed, for example, that in the case of a given alloy good results can only be obtained from vacuum melting, but that comparing several batches, the vacuum melt will inevitably be better, due to its consistency.

Other Processes

Vacuum techniques are not confined to melting alone—in fact it is difficult to see how they could be. There is little point in preparing metals free of gases in solution and then subjecting them to treatment which will restore the gas. Annealing, for example, if carried out in certain atmospheres will result in gases being absorbed, as will chemical descaling and plating. In both these latter processes the nascent hydrogen, if produced, may seriously affect the treated product. Vacuum annealing will give a product which does not require descaling and, in many cases, will give a product which has been cleaned by the process due to surface deoxidation, also certain products may have their hydrogen content substantially reduced by a suitable vacuum treatment.

In a similar manner the above-mentioned phenomena, when applied to vacuum sintering, contribute to an improved powder metallurgy product.

Heat treatment in general can be carried out more cheaply *in vacuo* than in a so-called inert atmosphere, and is particularly useful for metals like titanium and zirconium. The process which shows the most significant results, however, is brazing. This operation can be carried out in a high vacuum without flux—since in most cases the oxide film is automatically broken down—and thus there is no danger of inclusions or need for subsequent cleaning. Excellent wetting is assured, in fact it is possible to allow the brazing metal to be drawn upwards into a joint.

The utility of vacuum brazing was recently emphasized in the production of one of the company's own components. This was a vacuum valve assembly employing four dissimilar metals, and the construction was such that internal access for subsequent cleaning was impossible. Results, however, were entirely satisfactory. Brazing has also been successfully carried out on titanium and the entire range of Nimonic alloys, of which the latest varieties, having the higher numbers, have a particularly difficult oxide film.

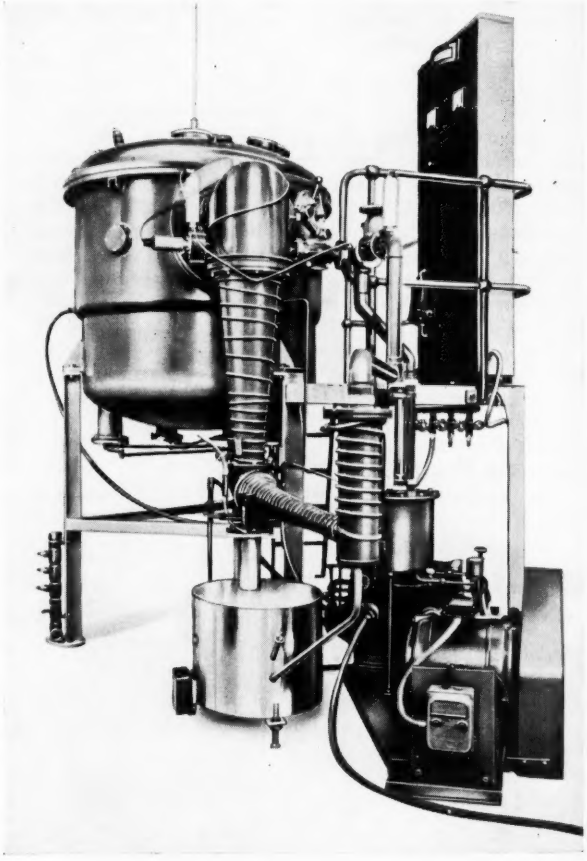


Fig. 1. An Efco-Edwards 56 lb. furnace.

The considerable experience and research facilities of the two member companies in their respective spheres has been integrated to produce an ever-growing standard range of vacuum metallurgical equipment.

Laboratory Furnace

The smallest furnace in the range is a small mobile laboratory unit for a ½ lb. melt, fitted with a resistance heating element. The vacuum chamber is of electro-plated mild steel, with a removable lid, both lid and chamber being water-cooled with external cooling coils. Vacuum sealing is by means of an "O" ring seal between the mating flanges. The

* Efco-Edwards Vacuum Metallurgy Ltd., representing a fusion of interests between the Electric Furnace Co. Ltd., and Edwards High Vacuum Ltd.

tilting furnace-pot assembly which can be seen in Fig. 2, is trunnion-mounted on a transverse shaft, arranged for tilting by an external handle. The pot itself is of stainless steel and contains the refractory crucible, surrounded by its heating element and a number of concentric cylindrical radiation shields, the three inner shields being made of molybdenum and the outer two of nickel. A stack of circular shields forming, in effect, a movable top cover, is attached to a pivoted lever, and can be swung into place or removed by rotating the pivot, which is carried through the seal in the lid and is arranged for external control. The lid also carries two observation windows which can be covered from the inside by a swinging shield operated by the top radiation shield mechanism.

The mould is trunnion-mounted from the pot assembly, thus remaining vertical whatever the angle of tilt. A refractory channel is provided to stop the molten metal touching the radiation shields while pouring and a stainless-steel splash shield also covers a portion of the side of the chamber. A small molybdenum chute on the side of the crucible opposite to the mould enables additional material to be added to the melt by a slight shaking movement of the pouring handle. In these smaller furnaces, the vacuum chamber is placed directly over the pumping unit, a gauze screen being interposed so that should splashing take place, metallic particles will not enter the pump.

The pumping equipment, constructed as a mobile self-contained unit, consists of an Edwards Speedivac diffusion unit with a speed (unbaffled) of 300-350 litres/sec. backed by a rotary pump. This combination gives ample pumping speed for the range of 10^{-3} to 5.10^{-5} mm Hg, normally used for most operations, but an ultimate pressure of 5.10^{-6} mm Hg is obtainable when required.

The vacuum system is fully valved so that the vapour pump can be isolated under vacuum while the chamber is open to atmosphere or while rough pumping so that it is not necessary to wait for cooling down or warming up of the diffusion pump, thus saving a great deal of time.

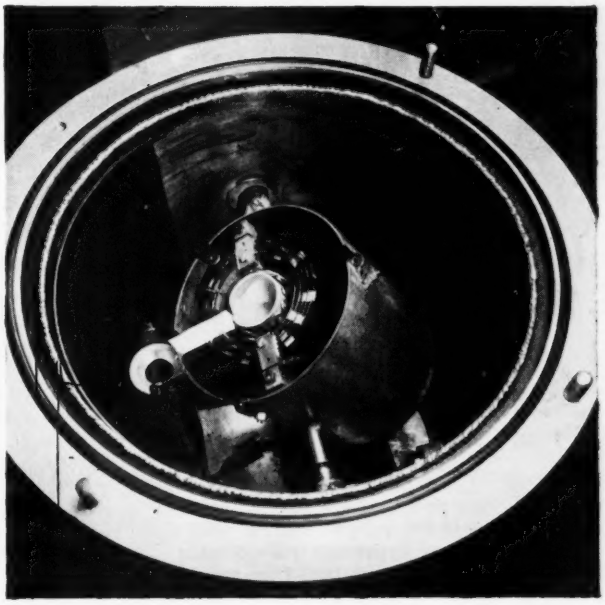


Fig. 2. Interior of the vacuum chamber of a ½ lb. furnace showing tilting pot and mould.

The power and control unit, also castor-mounted, carries the transformer and Variac control for the furnace unit, which is wound for 24 V and has a loading of approximately 2 kW. This unit also carries the Philani pressure gauge.

The Larger Units

The larger sizes of furnace are normally fitted with the Edwards Speedivac booster diffusion pump which has been designed to fill the "gap" between 1.0 mm Hg and 10^{-3} mm

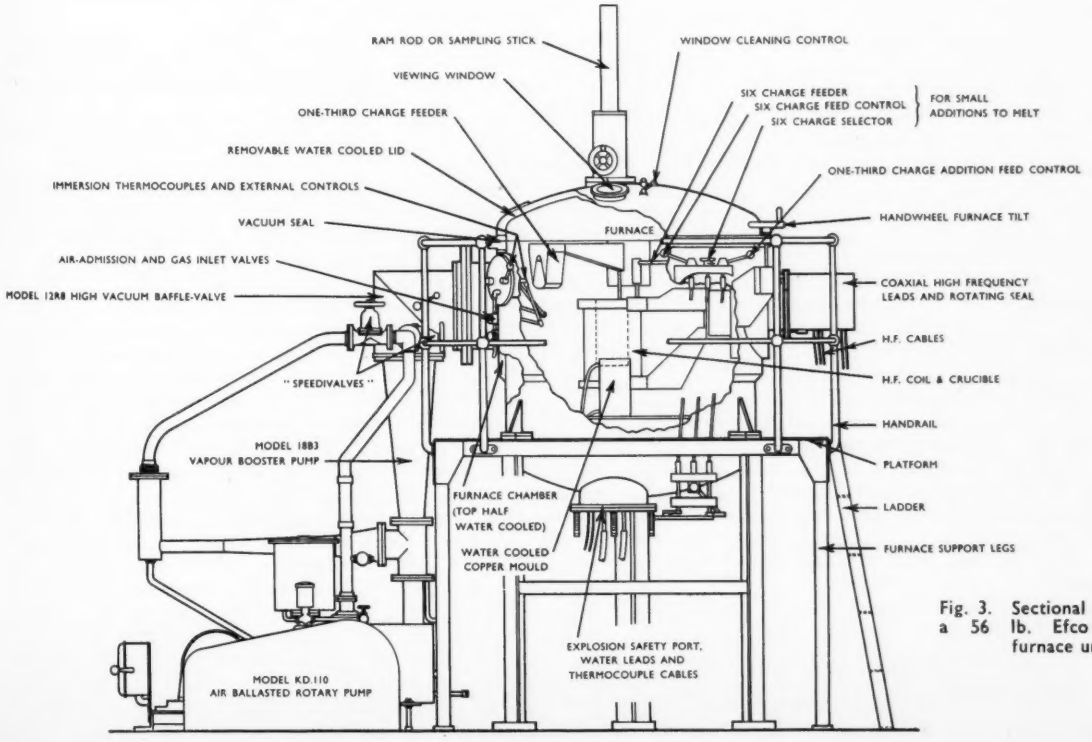


Fig. 3. Sectional drawing of a 56 lb. Efco - Edwards furnace unit.

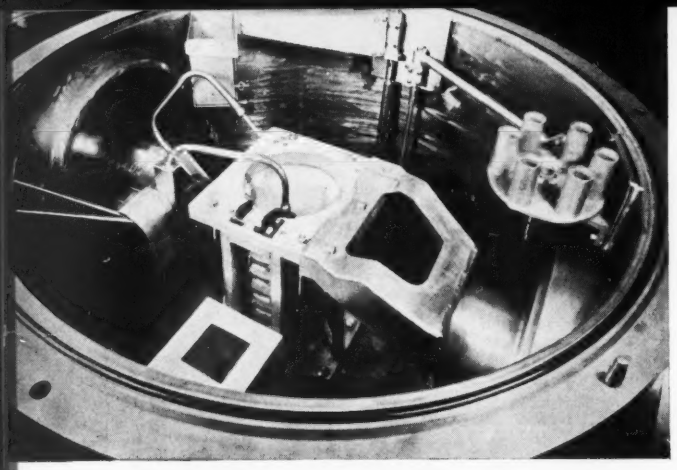


Fig. 4. Interior view of a 56 lb. unit, showing one thermo-couple in the "dipped" position.

Hg, where the rotary pump is losing its efficiency and the normal type of diffusion pump has not yet reached its full effectiveness. By giving high-speed pumping over this range, the booster-diffusion pump enables large volumes of gas to be handled on rapid operating cycles.

A unit suitable for a 56-lb. melt is shown in section, in Fig. 3. This is of considerably larger size, the chamber having an internal diameter of 3 ft. 9 in. Induction heating is used, the operating frequency being about 5,000 c/s, from a motor alternator set provided with switched capacitors for power factor correction.

The power rating is 50 kW for a 56-lb. furnace and 30 kW for a 28-lb. furnace, which is accommodated in the same size chamber as the larger capacity.

The large furnace has many refinements which are not practicable on the ½-lb. furnace. Up to one-third of the charge may be added after melting is under way, by an internal charger unit consisting of a bottom-discharge hopper box on a swinging arm controlled from outside. For the addition of alloying elements as and when required, up to six different charges are stored in the compartments of a rotary magazine. External controls select any one of the six compartments and automatically discharge its contents into a second swinging hopper which transfer it to the crucible.

The crucible unit is arranged for tilting by means of a handwheel and chain drive, although motor operation can be provided. The lid of the vacuum chamber is normally arranged for lifting by block and tackle on a monorail, but self-contained lifting and slewing equipment can be provided if necessary. Both the lid and the upper half of the vacuum chamber are of double construction, to provide water-cooling jackets.

An additional refinement on this size of furnace is the provision of a telescopic swivelling poker unit in the centre of the lid; the poker is of hollow construction to enable, say, hydrogen to be blown on to the surface of the melt for a purification process. The main use of the poker, however, is for overcoming bridging of the charge, although it can be used in conjunction with a small sampling dipper attachment.

A viewing window is also fitted in the lid. This is of double construction for protection should a glass happen to crack. To guard against this occurring the window is normally protected by a radiation shield which can be swung aside when required. The inside of the window can be cleared when desired by a wiper unit, operating in conjunction with a film of oil having a very low vapour pressure. Temperature measurement is by two thermocouples mounted on pivoted arms so that they can be dipped into the crucible at will.

The bottom plate of the vacuum chamber is fitted with a spring-loaded explosion port, in case of a sudden ebullition causing a momentary pressure rise. This is considered preferable to a rupture disc, since operation does not shut down the unit but the port can reclose after pressure release and allow the operation to continue.

In this size of furnace the mould, which may be water-cooled or hot-topped, stands on a platform instead of being suspended from the tilting unit. A lip-pouring crucible is used.

The present standard range of melting furnaces is completed with two production size units of 5 cwt. and 1 ton capacity.

They operate on similar principles to those described for the 56-lb. furnace and, in common with that furnace are designed throughout with an eye to future requirements, ample space being allowed for future modifications. In particular the furnaces may be readily converted to semi-continuous operation by means of vacuum locks fitted to existing ports. Such a conversion enables production to be carried on without the necessity of removing the lid and repumping for each cycle.

It is felt that in the future there may be a demand for a 10-cwt. furnace and for a 10-lb. size, being intermediate between the "baby" ½ lb. and its much larger 28-lb. brother.

Melting of Uranium

Mention has already been made of the applications of this technique to atomic energy, and uranium melting is a case in point. Uranium, however, introduces additional problems. As is well known, the oxide of uranium is very difficult to reduce and when high-purity uranium is required it is necessary to allow the oxide to float upon the surface of the melt and employ a bottom-pouring crucible. The difficulties of arranging to tap a crucible at the bottom by remote control can readily be seen, but they have not been found insurmountable. Complete details of the scheme have not yet been released but it is known that the new method developed lends itself to semi-continuous production and does not involve the flow of the metal over sealing surfaces, nor does it involve mating of ground surfaces.

Heat Treatment Furnaces

For heat treatment generally, resistance furnaces are used with a series of radiation shields similar to those described for the ½-lb. furnace, up to temperatures of 1,300°C to 1,400°C. Two furnaces are available in this range having work spaces of 10 and 40 litres capacity.

Above this temperature range a furnace is available that utilizes R.F. heating with a graphite or metal susceptor, temperatures of over 2,000°C being readily obtained in this manner.

The Arc Furnace

A further development is the metallic arc furnace, which should prove of considerable value in the refining of metals which, like titanium and zirconium, for example, are either contaminated by refractories or attack them.

A laboratory furnace is available utilizing both the "non-consumable" and "consumable" electrode techniques. In the non-consumable electrode version the arc is struck between the metal to be melted and a tungsten electrode. Evacuation to a low value is followed by the addition of an inert gas, and the process is carried out in this atmosphere.

The "consumable electrode" version has the metal to be refined in the form of a long electrode, continuously fed into the arc in a high vacuum, the metallic vapour providing the necessary conducting path to sustain the arc. The anode is provided by a water-cooled copper mould and the metal is merely transferred from the cathode to the anode, being de-gassed in the process. Some remarkable specimens have been produced in this way, one of the most striking being a mild steel ingot which, cut in half and polished, still retains very nearly a mirror finish after some eight months of knocking about in a box of scrap, the original electrode being covered with rust within a few days. There appears to be practically no limit to the capabilities of this type of furnace, which is now being manufactured on a production basis.

World News

The British Ambassador to Mexico, Sir William Sullivan (centre), talking to Mr. D. J. Muskett, commercial manager of the Amersham Radiochemical Centre, at the International Congress of Radiology in Mexico City.

INTERNATIONAL

At the Eighth International Congress of Radiology, held in Mexico City from July 22 to 28, considerable interest was aroused by the exhibit of the Radiochemical Centre, Amersham, which showed a range of more than 700 isotopes, and demonstrated the remarkable speed it can achieve in getting its products to the user. Central America can be reached in two days and South America in four days by air. Serious inquiries were received from 38 different countries during the course of the Congress.

The International Congress of Genetics ended its first meeting in Copenhagen on August 6. The resolution adopted at the meeting declared that the damage produced by ionizing radiation on hereditary material is real and should be taken seriously into consideration both in the peaceful and military uses of nuclear energy as well as in all medical, commercial and industrial practices in which X-rays or other ionizing radiations are employed. It is recommended that the investigation of the amount and type of damage and of related genetic questions be greatly extended and intensified with a view to safeguarding the well-being of future generations.

This broad statement covers the very considerable disagreements that exist on the levels of exposure that are significant from the genetic point of view. At a subsequent study group organized by the United Nations World Health Organization, set up to formulate recommendations to combat dangers arising from the increasing peaceful use of atomic energy, Professor Stevenson of Queens University, Belfast, is reported as calling for specific suggestions concerning lines of research which would be helpful if undertaken on an international basis.

The Anglo-German agreement signed on July 31 is for a period of ten years and enables the Federal Republic of Germany to obtain research reactors from Britain, and unclassified information concerning their design, construction and operation. Facilities for training will, where possible, be provided by the Atomic Energy Authority.

Provision has been made in the agreement for safeguards to ensure that materials and information supplied will be confined to peaceful uses. Further consultation is foreseen, after the setting-up of the proposed International Atomic Energy Agency, regarding the possible application of agency controls, since both parties are supporters of the scheme.

Seventh nation to join Euratom. Recent responsible statements in France have freely forecast that the six member nations of Euratom would be joined by a seventh. No direct indication has been given of the seventh nation but France is particularly anxious that the United Kingdom should become a full member. It is more probable however that Euratom would be augmented by either Denmark or Spain before the United Kingdom would become a full participant.

UNITED KINGDOM

Irradiation of diamonds for commercial purposes will now be undertaken by the A.E.R.E., Harwell, so far as other demands on the irradiation facilities allow. Hitherto, the Authority has restricted this facility to small quantities of diamonds for fundamental research purposes only.

AUSTRALIA

First private-enterprise power plant in Australia is being considered as a possibility by Mount Isa Mines Ltd. Located in North-West Queensland, Mount Isa's existing power plant pays £A8 per ton for coal which has to be hauled 760 miles from the coast and is believed to be the most expensive coal in Australia. According to a Reuter report from Brisbane, the proximity of rich deposits of uranium oxide does not affect the question, as the processed fuel would have to come from Britain or the U.S.A.

CANADA

Shipments of isotopes totalled 1,500 during the year, according to the annual report of Atomic Energy of Canada Ltd., recently published. This marks an increase of 400 over the previous year.

Nine thousand tons per day of uranium oxide are to be produced by the Northspan mines, under the terms of a contract awarded by the Canadian Government's agency, Eldorado Mining and Refining Ltd. The contract, described as the world's largest, is said to be worth more than £86 million. Northspan is a subsidiary of Rio Tinto of Canada Ltd.

CUBA

Electricity. Electric power demands over the first four months of 1956 were nearly 37½ million kilowatt hours higher than in the same period of 1955.

The American Foreign Power Company, which owns the Cia. Cubana de Electricidad, has announced that it is to spend $147 million in an expansion programme in Cuba over the next five years. The plan includes the installation of an atomic power plant, the doubling of the company's generating capacity, an intensified study of the role which electric power can play in Cuba's economy, and an expansion of the employees' training programme here. Approximately half the money will be spent in Cuba on labour and materials.

GERMANY

Hamburg reactor. Negotiations for Germany's third research reactor are reported as complete. This is to be built at Hamburg and a recent Reuter statement places the cost at around £375,000. The reactor is partly sponsored by the Federal Government and partly by the Government for the four coastal provinces

Signing the Anglo-German Agreement at the Foreign Office. (Left to right), Sir Edwin Plowden, Mr. Selwyn Lloyd, Herr Franz Joseph Strauss (Federal German Ambassador) and Herr Hans von Herwath (Federal German Minister for Atomic Affairs).

and by the West German shipping and shipbuilding industry. Earlier statements indicated that the reactor to be constructed at Hamburg would be supplied by Babcock and Wilcox of America and the figure quoted was in the region of $450,000. It is believed the difference between these two figures is made up by the civil engineering work required on the site for excavations and buildings. The reactor is of the swimming pool type with a maximum design rating of 5 MW heat. Delivery time for the complete plant and associated equipment is in the region of 12 months and the reactor is expected to become critical by next summer.

Draft legislation for the German atomic energy programme has been approved by the Federal Cabinet. Details of the proposals have not yet been made public but Herr Strauss, the Federal minister for atomic questions, has given reporters to understand that the bill has been designed to give industry every encouragement to develop its own ideas and its own plant. Although import and export of fissile material and transport within the Republic and certain aspects of its handling will require licences the general principle of ownership of fissile material by private companies is approved. This bill is designed to deal solely with atomic energy for peaceful purposes, the weapon side of the programme being left to the Government in the hands of the Ministry of Defence. A second bill which has received approval by the Federal Cabinet modifies the existing law defining the responsibilities of the central government and the Länder. Both these bills will come before the Bundestag in the Autumn.

A uranium mine in the mountains east of Bayreuth is stated to be under development by the atomic energy ministry. Preliminary reports indicate that an output of 10 tons of uranium metal can be expected annually for the next five or ten years. Further exploration for uranium is to be encouraged by the Federal Government and 2½ million marks (£200,000) has been set aside for this purpose.

A research reactor for West Berlin was reported on July 24 to be on order in the United States. This will be the first of two, the second being a larger model of, at present, unspecified type and size. West Berlin at present geographically cut off from the rest of Germany has decided to establish its own research institute and has allocated over £100,000 for this purpose. This sum will be increased by another £800,000 by 1959.

INDIA

A two-day conference for scientists from India, Burma, Ceylon, Indonesia and Egypt began in Bombay on July 24. The purpose of the meeting is to discuss systems for closer co-operation in the development of atomic energy for peaceful purposes and for linking the programmes of the five countries to avoid the duplication of effort. The conference which was held under the chairmanship of Dr. H. J. Bhabha made good progress in the establishment of a common policy and have agreed to hold further meetings which will if possible include other countries of Asia and Africa.

The first nuclear reactor in Asia became critical on August 4. The reactor is of the swimming pool type and is located in the outskirts of Bombay at Trombay. The reactor has been built to give experience to scientists training in nuclear engineering and to produce radio-isotopes for research into agriculture, biological and industrial problems. At a press conference held that evening Dr. Bhabha, chairman of the Indian Atomic Energy Commission, emphasized that the reactor was an entirely Indian effort built by the engineers of the I.A.E.C. The fuel elements, however, were not fabricated in India but were bought from the U.K.A.E.A. In his comments on the excellent progress that India was making in the atomic energy field Dr. Bhabha pointed out that the construction of the reactor has been completed within a period of one year, whereas the United Kingdom had begun to build a similar reactor at the same time (LIDO) and this was not yet in operation.

JAPAN

British reactor? Latest Reuter reports now affirm that the Japanese Atomic Energy Commission has decided to begin preliminary negotiations for the purchase of a British reactor for the generation of electric power. This is to be a gas-cooled, graphite-moderated reactor with a generating capacity of 100 MW. The J.A.E.C. is reported as announcing that a team of ten Japanese have been invited to tour British atomic energy installations for three weeks starting October 21, and that negotiations for conclusions on the agreements would be started before the end of the year.

Work on Japan's atomic research centre at Tokai village, 60 miles from Tokyo, was officially commenced on August 10, when the chairman of Japan's Atomic Energy Commission, Mr Matsutaro Shoriki, broke the ground at a 900-acre site. It is stated in a Reuter report that the Commission's 15-year plan provides for the installation of eight reactors of various types, commencing with an experimental reactor to be installed by next March and a boiling-water reactor by 1958. The year 1958 would also see the installation of a 100-MW British power reactor, according to a spokesman of the Commission.

According to a Reuter report from Tokyo on August 18, the Commission was about to ask the Government to approve a budget of £12 million for the coming year against the current budget of £3·6 million. A list of objectives has been drawn up aimed at making Japan self-sufficient in atomic energy and, in addition to a comprehensive training plan for technicians, the programme includes investigation of the possibility of counteracting harmful radiation effects.

High purity uranium has been produced by an electrolytic process at a cost of 2,000 yen (£2) per kg according to a Reuter report from the Japanese Government Technology Board.

Marine nuclear power is being considered by Osaka Shosen Kaisha who have submitted a five-year plan for the construction of a vessel with a 20,000 h.p. nuclear plant to the Japanese Atomic Energy Commission. According to a Reuter report, the vessel, of 20,000 tons and a speed of more than 25 knots, would be designed and built by themselves, the propulsion machinery being built abroad. It is estimated that such a vessel would

cost about twice as much as one with conventional engines.

UNITED STATES

Construction of a reactor-powered ship has now been authorized by Congress. The project is estimated as costing about $40 million of which the Maritime Board will provide $18 million and the A.E.C. $22 million, these being the respective costs of the hull and the nuclear power unit. At a press conference the head of the Federal Maritime Board, Mr. Morse, stated that he hoped that contracts would be placed for the whole construction by early next year but that the reactor power unit would probably take three years. Possibilities of building a power unit similar to that installed in the submarine *Nautilus* would be considered from the legal angle. It is probable however that a more advanced type of reactor would be considered. In answer to questions Mr. Morse affirmed that the project could not expect to result in an economic propulsion unit. No decision has yet been taken on whether the ship should be a purely cargo vessel or a combination cargo-passenger. In addition to technical discussions, many questions affecting all international shipping would have to be settled before final plans could be drawn up. The sinking of the Italian ship *Andrea Doria* has emphasized the vulnerability of even the most modern unsinkable ships and the problems that would arise by a major accident in coastal waters must receive the greatest consideration before final decisions are taken on the details of the power unit.

An additional $24 million has been allocated to the Atomic Energy Commission for reactor development and military development. Of this approximately $15 million will go towards the expansion of the reactor development programme and about $9 million for the construction of facilities and sites for military projects. Details of these projects have not been made public.

Aero-Jet General Nucleonics is a company which has been formed by the absorption of the Applied Nucleonics Corporation into Aero-Jet General Corporation. As a result of this tie-up the new company has resubmitted the licence applications to the U.S.A.E.C. for permission to build a small research reactor. This reactor of 100 milliwatt net output is designed to use fuel elements composed of 20% enriched uranium oxide embedded in radiation-stabilized polythene — 600 grams of UO_2 in all. The polythene acts as moderator in the reactor and it is hoped that this system of fuel element construction will be adaptable to other reactor designs.

Westinghouse Electric has received the contract from Consolidated Edison Company, New York, for the supply of the turbine generator equipment to the Indian Point nuclear power plant. Capacity of this plant is 236 MW electrical output and the contract is valued at $8 million.

New York Shipbuilding has been awarded a contract by General Electric Company for the reactor pressure vessel for the Commonwealth Edison Company's Dresden nuclear power station near Chicago. This reactor of 180 MW electrical output is of the boiling-water type. The contract is stated to be worth $2 million.

Sterilization research is being extended by the Armour Research Foundation, Chicago, to cover sewage. This is potentially a large field for the utilization of waste fission products and may form a very valuable commercial outlet. The Army Applied Ionization Centre is to be provided with a $3 million research reactor by the U.S.A.E.C. according to plans being drawn up by the Quartermaster Corps. In addition, a 20-MeV linear accelerator is to be installed. The Centre will have a food irradiation capacity of 1,000 tons per month, and should enable research into the value of radiation sterilization of foodstuffs to be speeded up very considerably. Contracts for the construction of the Centre are being considered.

Dr. Michael N. Pobedinsky, chief of the Russian delegation to the Eighth International Congress of Radiology, held in Mexico City, talking to Mr. D. V. Muskett.

The Fifth Conference of N.I.C.B., the National Industrial Conference Board, has been put forward to March 14 or 15, 1957, to coincide with the second nuclear engineering session of the Engineering Joint Council. The conference which is specifically for business executives in the atomic energy field will be held in the Benjamin Franklin Hotel.

Orbits in Industry

Tribute To One Pioneer . . .

Engineering history contains so many gaps that it gives genuine pleasure when someone takes the trouble to fill one of them. There is not enough room in the engineers' pantheon to provide a niche for every one who breaks new ground; one cannot have too many Faradays, Edisons or Curies. On the other hand, many a pioneer is relegated to the anonymous ranks of the forgotten men while the world accepts his discovery as a matter of course. A modest sheaf of typescript received from Acheson Colloids Ltd. reminds us that 1956 is the centenary of the birth of Edward Goodrich Acheson, who gave us, amongst other things, two materials of widely different properties: carborundum and graphite, both produced in the electric furnace.

A rolling stone in his younger days, Acheson was at one time an assistant of Edison, and had Nikola Tesla as his junior, and he turned down the offer of engineer at the Pearl Street station to go into business on his own account. The importance of carborundum can be judged by its inclusion at the Philadelphia Exposition in 1926, along with the telephone and the sewing machine, amongst the 17 patents which the U.S. Patent Office judged to be the most useful to mankind, while nuclear engineers are well fitted to assess the value of graphite.

. . . and Others

Acheson, of course, was the pioneer of manufactured graphite. By another odd coincidence, this year also marks the centenary of a major expansion in the use of natural graphite. It was in 1856 that the Brothers Morgan—then "Druggist Sundriesmen and Hardware Merchants"—entered into the manufacture of crucibles from "blacklead," in a shady nook among the

green fields of Battersea. Their story is told in a book called *Battersea Works*, previously noted in these pages and well worth reading—if you can get a copy.

Nickel Mining

While on the subject of centenaries, it is also just a century since the richest nickel ore deposits in the world were first discovered at Sudbury, Ontario. By courtesy of the Mond Nickel Co. Ltd., we were able to see the first European showing of *Mining for Nickel*, a film made for their Canadian parent company, International Nickel of Canada Ltd., who do just that very thing to the tune of 15,000,000 tons a year from 400 miles of underground workings. The film, which is in colour, took two years to make, and used "expendable" (lovely word!) cameras to take some of the blasting shots, one of which moved half a million tons of ore. Nuclear engineers nowadays, however, spend so much of their waking time thinking about metals with names ending in "onium" that they may be apt to forget the importance of the nickel group in the more conventional parts of their plants; notably in alloys for high performance.

Nivco

Strangely enough, on the very day of writing the above paragraph, news reached us of a new "super alloy" by the Pittsburgh laboratories of Westinghouse which is principally nickel and cobalt with small amounts of five other—undisclosed—elements. It is a creep-resisting material with an ultimate tensile strength of 100,000 lb./sq. in. at 1,200°F, which is no mean performance; but it is also claimed to possess a magnetic structure that damps out vibration, and is said to have been "pre-designed" by a new metallurgical technique that enables one to build in, as it were, the necessary properties to an alloy before it is actually made. The particular interest that the account had for this column, however, is that it was produced in a vacuum furnace; another happy coincidence, in view of the article on page 252.

Sand and Shot

History, in spite of what we are told, does not always repeat itself, but it is remarkable how often an incident reminds one of a previous happening, even though the circumstances are quite different. This perhaps-not-so-profound thought arose during a visit to the Vacu-Blast works to see their latest unit (page 261) on hearing that the originator of the system, an American citizen by the name of Blackburn, thought of the idea while playing with his wife's vacuum cleaner at 3 a.m. He was seeking the answer to a problem posed by the Bethlehem Alameda shipyards, who could not get composition tiles to stick to steel decks and foresaw some difficulty in putting the ship into a shot-blast cabinet. Strangely enough, it was a chance incident that first brought the shot-blast principle into being in the first place. Over eighty years ago, General B. C. Tilghman was pondering over the frosted appearance of the windows of a house standing in a windswept prairie and the idea of the sand-blast was born and patented in 1870. Originally intended for etching ornamental patterns on glass, the sand-blast became indispensable to the engineering industry, until the sand was replaced by steel shot because of the danger of silicosis. As shot-blasting, it became even more an integral part of engineering. So, incidentally, did the name of its originator.

Accelerators in Industry

That electrical conundrum, the Van de Graaff machine, appears to be achieving popularity amongst the ever-growing band of those who feel that no laboratory is complete without a particle accelerator. It is interesting to speculate on the length of time which must elapse before the accelerator becomes a commonplace part of the production line. Standard Telecommunications Laboratories, whose installation is described on page 250 of this issue, regard their machine as a research tool at the moment, but have already carried out some interesting work which would enable it to become part of a production routine. A magnetic beam-splitting and reflecting system has been worked out that makes it possible to irradiate both sides of an object at once, so that if it were desired to work on a cable dielectric it could simply be reeled through the machine and finished in a single pass.

Irradiated Rubber

Irradiation of materials, as carried out by Dr. Charlesby of Tube Investments Ltd., and others, seems to offer very promising results. The Dunlop Research Centre at Birmingham has just installed a new laboratory for this work, this being the first in the rubber industry. Here, however, irradiation is to be carried out with an isotope source, although the future installation of a particle accelerator has not been ruled out. Work is commencing with a 100-c unit of cobalt-60, although a full source of 1,000 c is to be installed at a later date.

House Full?

The choice of the Civils lecture theatre as the venue of the forthcoming B.N.E.C. meeting in November is appropriate in theory, but does not seem very practical, from the space point of view, unless the attendance is considerably smaller than it was at the first conference. All of the institutions have outgrown their seating capacity, and occasions like this show it only too plainly. It has been suggested that a theatre should be hired, in the same way as the Playhouse at Oxford has been used for the International Isotope conferences. Or the Central Hall is reasonably near all three of the institutions.

A further suggestion, however, for what it is worth, is the splitting-up of the party into three, the two overflow parties being not just parked in an adjacent room with a loudspeaker, but accommodated in the lecture theatres of their own institutions and connected up by closed-circuit television. If British Oxygen can run a "Press visit" to their new tonnage oxygen plant at Margam by this means, the combined technical resources of three institutions should be equal to it. Or are the B.N.E.C. authorities counting on a smaller attendance? Perhaps they feel that the £1 entrance fee (which is causing some adverse comment) will keep out the riff-raff.

Instrument Service

Worthy of comment is the move recently made by Electronic Instruments Ltd., of Richmond, in opening a service centre in Bradford (at 8 Duke Street). Not only is this equipped with full repair and spares facilities, but it has a fleet of motor vans whose principal duty is to pay regular visits to inspect the installations of pH equipment, one of the company's major products. A "pHlying" squad, in fact.

Plessey in U.S.A.

Reversing the usual order of things, the Plessey Co. Ltd. has just formed an American corporation to look after its interests in the U.S. Known as Plessey Inc., it has been incorporated under the laws of Delaware, and has offices at 41 East 42nd Street, New York City. It will handle all American affairs, and Plessey's Chicago offices are being closed down.

Applied Electronics

A sign of the growing importance of electronics in the world of today is given by a recent communication from the General Electric Co. Ltd., who point out that three of their laboratories are known as "Applied Electronics". The establishments in question are those at The Grove, Stanmore, Middlesex; Brown's Lane, Allesley, Coventry; P.O. Box 127, Salisbury, South Australia.

Prices

A communication from the British Laboratory Ware Association Ltd. states that their member firms have pledged themselves to maintain existing prices for a sixth-months' period. This praiseworthy effort towards price stability is a move that all would like to make, but some are unable to do so. For example, British Oxygen Gases Ltd. have been compelled to raise their tuition fees for all their oxy-acetylene welding courses. From September 1 these courses, which have hitherto cost £7, will be £10. This advance, due to the increase in cost of materials used during the course, will not do much to raise the dividends, however. The courses have been run at a loss since 1935—they still will.

Change of Address

The British Insurance Association, formerly of 66 Graham Street, London, E.C.2, points out that from August 7 its address is 59-67 Gresham Street. The telephone number, MONarch 4966, remains unchanged.

COMPANY RESULTS

Gross profits of the John Thompson Ltd. group of companies for the year ended December 31, 1955, were £2,113,866. In his report, the chairman, Mr. Edward W. Thompson, dealt at some length with the company's interest in nuclear engineering and its association with Associated Electrical Industries Ltd. in reactor design and construction.

Personal

Sir Richard Fairey, M.B.E., Hon. F.R.Ae.S., has resigned the office of managing director of the Fairey Aviation Co. Ltd. but remains executive chairman of the company. **Mr. Geoffrey W. Hall,** A.F.R.Ae.S., formerly an assistant managing director, has been appointed managing director. **Mr. L. Massey Hilton,** D.F.C., A.F.C., A.F.R.Ae.S., has relinquished office as assistant managing director but remains on the board.

Mr. L. Redshaw, M.Eng., M.I.N.A., M.Inst.W., has been appointed an additional member of the board of directors of Vickers-Armstrongs (Shipbuilders) Ltd. He will retain his present office of shipbuilding general manager of the company.

Mr. J. T. W. Dewar has been appointed an additional director of the English Steel Corporation Ltd. Mr. Dewar is deputy managing director of Firth-Vickers Stainless Steels Ltd., and managing director of Shepcote Lane Rolling Mills Ltd., both of which appointments he will retain.

Mr. P. Ralph has been appointed vice-president of Aluminium Transatlantic Inc., it is announced by the British Aluminium Co. Ltd. **Mr. R. A. Martin** has been appointed manager of the British Aluminium Company's Scottish branch sales office in place of Mr. Ralph.

Mr. C. J. Mole, A.M.I.E.E., formerly with the English Electric Co. Ltd., has taken up an appointment as consultant with Peregrine and Partners, consulting engineers.

Dr. William J. Bennett, O.B.E., president of the Atomic Energy of Canada Ltd., has been awarded an honorary degree by St. Francis Xavier University, Antigonish.

Mr. E. W. Bussey, C.B.E., will resign from his position of chairman of the employers' side of the joint negotiating committees covering the Electricity Supply Industry of the Central Electricity Authority, on December 31, 1956.

Mr. T. B. Webb, B.Sc., M.I.Mech.E., has been appointed chief engineer and manager of the newly-formed Atomic Energy Department of Babcock and Wilcox Ltd. **Mr. W. R. Wootton** becomes assistant manager. The Department becomes operative on October 2 and will, under the direction of the company's chief engineer, **Mr. W. F. C. Schaap,** be responsible for continuing development, project and contract engineering in the nuclear-energy field. The position of chief research engineer at Babcock and Wilcox's Renfrew establishment, vacated by Mr. Webb, will be filled by **Dr. W. B. Carlson,** D.Sc., M.I.Mech.E., M.Inst.F.

Sir Archibald Gill, B.Sc., M.I.E.E., has joined British Telecommunications Research Ltd. as director and general manager. **Mr. J. Lawton,** M.Sc., M.I.E.E., and **Mr. G. T Baker,** M.Sc., have been appointed to the board of directors. **Mr. F. O. Morrell,** B.Sc., M.I.E.E., director of research, has been appointed engineering director of the Automatic Telephone and Electric Co. Ltd., which, with British Insulated Callender's Cables Ltd., jointly established British Telecommunications Research Ltd. in 1946.

Sir William Penney, who is in Australia for nuclear weapons tests, has been given the honorary degree of doctor of law of Melbourne University.

Mr. G. Keith Allen has been elected president of the Institution of Mining and Metallurgy for the year 1957-1958. Mr. Allen is at present Reader in Mining at the Royal School of Mines, University of London. **Mr. B. W. Kerrigan** has been appointed secretary of the Institution.

Mr. G. A. Whipple, M.A., M.I.E.E., F.Inst.P., has been installed as president of the Scientific Instrument Manufacturers' Association. Mr. Whipple has been vice-president for the past two years and is also the chairman and managing director of Hilger and Watts Ltd. **Mr. P. Goudime,** Electronic Instruments Ltd., was elected vice-president, **Mr. J. E. C. Bailey,** C.B.E., Baird and Tatlock (London) Ltd., hon. secretary, and **Mr. Chas. H. Warner,** W. F. Stanley and Co. Ltd., hon. treasurer. New members of council taking office at the same time were **Mr. F. W. Dawe,** Dawe Instruments Ltd.; **Mr. P. J. Ellis,** O.B.E., R. B. Pullin and Co. Ltd.; **Mr. J. M. Furnival,** M.B.E., Marconi Instruments Ltd.; **Mr. D. F. Newstead,** Rank Precision Industries Ltd.; **Mr. J. A. Stafford,** Taylor, Taylor and Hobson Ltd.; **Mr. W. H. Storey,** Unicam Instruments Ltd., and **Mr. N. Trepte,** Griffin and George Ltd.

Mr. E. T. Gill, B.Sc., F.I.M., has been appointed development officer for constructional alloy steels in the development and research department of the Mond Nickel Co. Ltd. Mr. Gill succeeds **Mr. L. W. Johnson** who has been appointed assistant manager of the department.

Mr. S. Polkinghorn, the general sales manager of the Compoflex Co. Ltd., has been appointed general commercial manager, with direct responsibility for both home and export sales. **Mr. J. Pickthall,** formerly Northern sales manager, is promoted to home sales manager and will be assisted by **Mr. C. V. Hadley,** in charge of the liquids handling side, and **Mr. H. J. Bergin,** non-liquids handling. The newly-formed export department will be under **Mr. A. R. Davies. Mr. R. A. Usher** is appointed service manager.

Mr. Harvey De Covnick has joined Radiation Counter Laboratories, Inc., as a nuclear reactor control systems engineer. Mr. De Covnick was formerly associated with Atomic International Division of North American Aviation Company. **Mr. Vernon L. Brown,** formerly associated with Magnavox, has been appointed senior engineer of RCL.

Mr. Thomas Benson Gyles has been appointed by the U.K.A.E.A. to act as liaison officer with industry over the question of patents. Mr. Gyles will also advise on the uses to which atomic energy inventions might be applied and the terms under which they can be used.

Mr. F. D. Hucklesby has been appointed superintendent of the process development section at the sales technical service department of the British Oxygen Co. Ltd., at Cricklewood.

Mr. J. B. Longman has been appointed technical sales representative for South London and South East England for the Baird and Tatlock group of companies. He succeeds **Mr. P. H. D. Andrews.**

Mr. W. T. Cooper, editor of the Journal and other publications of The Institute of Fuel, has resigned to take up the appointment of senior research officer of the Australian Commonwealth Scientific and Industrial Research Organization. He is also to succeed Mr. N. Y. Kirov as honorary secretary of the Australian Membership of The Institute of Fuel in January, 1957.

Mr. E. W. B. Lewis has been appointed treasurer by the board of directors of Westinghouse Electric International Co. and **Mr. J. P. Boyer** auditor.

Mr. G. W. Hall.

Mr. J. T. W. Dewar.

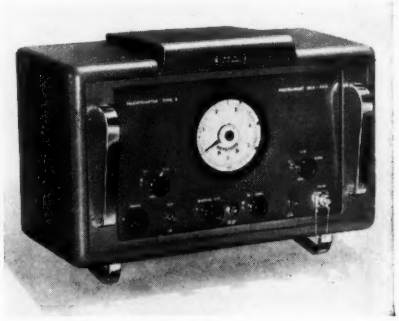
Mr. G. A. Whipple.

Mr. T. B. Webb

Mr. W. R. Wootton.

Dr. W. B. Carlson.

Processes and Equipment



Newport Instruments' new direct-reading magnetometer.

Neutron Shielding Alloy

Boral, a neutron shielding material which is said to give the shielding properties of 26 in. of concrete in a ¼-in. thick plate, is now commercially available in the U.S.A. Originally developed by the A.E.C. at Oak Ridge, it is being manufactured by Brooks and Perkins Inc., of 1,950 W. Fort Street, Detroit, 16.

Boral is rolled plate of sandwich construction, with outer cladding of commercially pure aluminium, and a core of a dispersion of boron carbide in aluminium, the grade at present offered having a 35% concentration of boron carbide. It is manufactured as a hot-rolled mill-finish sheet of ⅛ in. or ¼ in. thickness, with approximate total weights per sq. ft. of 1.7 and 3.4 lb. respectively, the amounts of boron carbide being 0.38 lb. and 0.75 lb. Standard sheets are 15 in. and 30 in. wide by 4 ft. or 8 ft. long., and the basic prices for quantities of not less than 240 sq. ft. are $12 and $16 per sq. ft.

Tube Bending without the "Long Arm"

The wide range of Staffa tube bending machines, marketed by Chamberlain Industries Ltd., has now been extended to include seven sizes of hydraulic draw benders for tube and pipe from 1 in. to 12 in. bore. One of the main features is that the conventional swinging arm that normally forms a part of this type of machine has been done away with, the tube being hydraulically clamped to the centre former by a short stroke ram. The required bending angle is set on an indicator pointer, which returns to zero and stops there automatically as the centre former rotates. Repetitive bends can be made without moving the pointer.

If required, a booster ram can be supplied to push against the end of the tube; this assists in bending to close radii with minimum thinning of the tube wall on the outside of the bend. An additional ram, in connection with a lifting davit, can be supplied to facilitate the removal of formers and dies on to trolleys, when changing tools for different work. The machines are marketed exclusively by Drummond-Asquith (Sales) Ltd., of Birmingham.

Triode for Stabilized Power Supplies

Mullard Ltd., of Century House, Shaftesbury Avenue, London, W.C.2, announce a new low-impedance twin-power triode, the 6080, primarily intended for use as a series regulator in electronically-stabilized power supplies or in servo amplifiers. Its outstanding feature is low anode resistance (280 ohms for each section at 125 mA) and consequent low voltage loss.

The 6080 has a heater rating of 2.5 A at 6.3 V. The amplification factor is 2, the slope being 7 mA/V for each section. Maximum anode current for one section is 125 mA, the dissipation being 13W. Balance between the triode sections is said to be good.

New Magnetometer

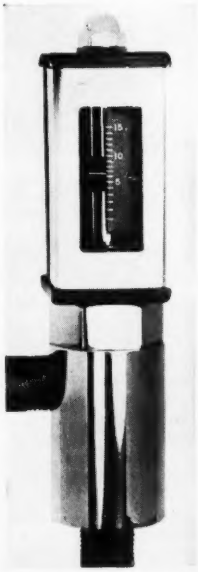
A direct-reading magnetometer which will measure fields from 0.1 to 500 oersteds with one probe has been developed by Newport Instruments (Scientific and Mobile) Ltd., of Newport Pagnell, Bucks. Originally developed for the measurement of variations in the fields of television focus magnet, it has been used with success on work in connection with particle accelerators. Direct readings in oersteds are given by a 4-in. circular scale instrument; output terminals are also provided so that a slowly varying field may be displayed on a pen recorder or an oscilloscope. An accuracy of better than ±2% is claimed and the probe is provided with a thermometer for temperature correction. The approximate price is £97.

Other Newport products recently marketed are a precision oscilloscope for quantitative measurements of pulsed or transient wave forms, and a high-performance precision electromagnet for basic research work, the latter giving field strengths of up to 10,000 oersteds at 2-cm. pole separation.

Flow Indicator for Hazardous Fluids

Brooks Rotameter Co., of Lansdale, Pennsylvania, have designed a new armoured flow indicator for use with hazardous fluids at elevated temperatures and pressures. Of simple construction, it has no glass parts in contact with the metered fluid, the flow rate being measured by the movement of a tapered plug in a fixed orifice. This movement is transferred by magnetic coupling to a

Left: The largest size of the new Staffa range of hydraulic draw benders for tube and pipe.

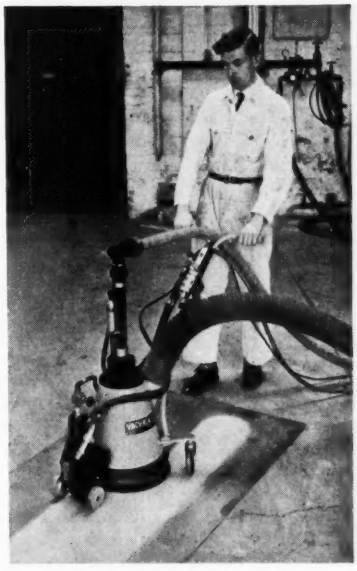


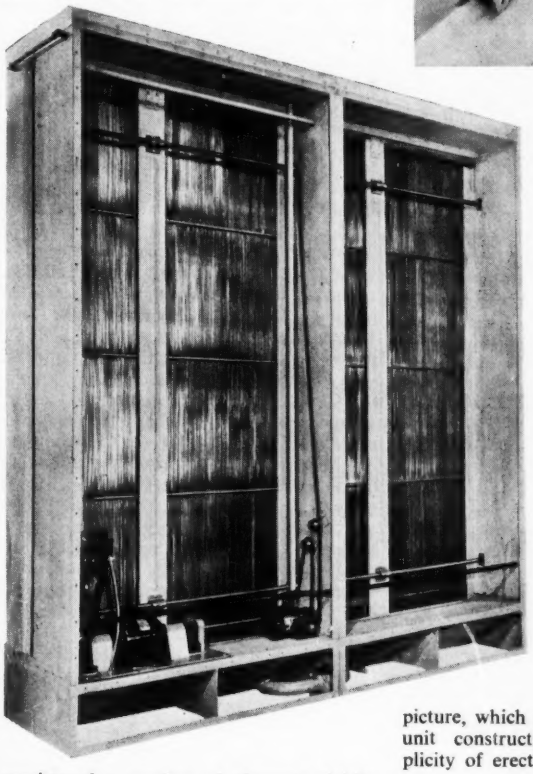
Right: The new Brooks Rotameter flow indicator for high-pressure work.

tubular follower outside the flow line, so that there are no packed glands, a simple "O"-ring seal being employed, and the entire meter may be dismantled for cleaning or change of range without removal from the pipe-line. Five standard plug and orifice sets are available to cover flow between 1½ gal./hr. and 180 gal./hr. in a single body size suitable for pressures up to 1,500 lb./sq. in. and 400°F. The normal construction material is stainless steel, but brass or carbon steel can be supplied if required.

Ventex Continuous Cleaning Filter

Salient features of the Ventex filter manufactured by Ozonair Engineering Co. Ltd., of the Esplanade, Rochester, Kent, are the continuous cleaning of the filter elements, the low air-flow resistance, the freedom from oil carry-over, and the low maintenance. A self-contained design, without auxiliary equipment, the Ventex





Above: The new Vacu-Blast high production gun unit at work. Note the air-operated traction unit at front.

Left: Rear view (clean air side) of Ventex unit for 33,000 cu. ft./min. at 0.3 in. W.G. Dimensions are 10 ft. 6 in. by 10 ft. wide.

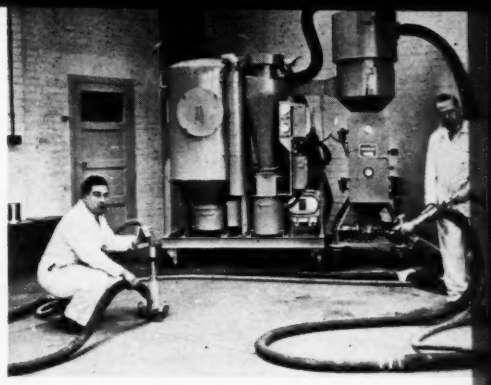
consists of a number of elements rigidly held in panel formation, with a moving curtain travelling slowly across the panel, driven by self-contained motors. The viscous fluid flows down behind the curtain and the speed of travel is such that there is time for adequate cleaning and draining before the particular section of filter comes into the air stream again. There is, therefore, no tendency for oil to be airborne, so that the unit is particularly recommended for reactors and other cooling systems where freedom from carry-over is as essential as reliability of operation. A further advantage is that, due to the continuous action of the cleaning unit, the resistance to the air flow remains sensibly constant.

Illustrated is a unit suitable for 33,000 cu. ft./min. at 0.3 in. W.G. From this picture, which shows the "clean" side, the unit construction and consequent simplicity of erection can readily be seen.

New Vacu-Blast High Production Gun

Although it is only a little over five years since Vacu-Blast Ltd., of 291 Aberdeen Avenue, Slough, Middlesex, commenced manufacture in this country their system of combining the vacuum and blast in a single nozzle head is already widely known; the ability to carry out dust-free shot blasting in the open, without protective clothing, possessing considerable advantages for many applications. They are now marketing a new high-production gun which gives an 8 in. wide track with each pass. Mill scale from flat plates can, it is stated, be removed at a speed varying between 300 to 600 sq. ft./hour, according to the condition of the surface.

The gun which, in this model, is fitted



Above: The Vacu-Blast Senior machine unit operating two standard blast heads.

with a wheeled carriage consists of a conical head, containing three ¼ in. blast nozzles, which rotates inside an outer cone forming the body of the machine. The annular space between the inner and outer cones is under a vacuum so that the shot, along with the scale and dust removed from the plate is instantly removed, a bristle seal being provided around the outer cone to restrict ingress of air from outside and ensure that the shot cannot escape.

Flexible hoses connect the machine with the main supply unit which, for this type of head, is the Senior model, carrying the exhaust fan, together with the reclaimer, cyclone, and shot storage containers. The machine is designed for continuous cycling, the dust being separated from the shot and retained within a collector unit, the air being filtered before discharge and the shot recirculated. Compressed air at about 100 p.s.i. is required; the consumption being some 260 cu. ft./min. at this pressure. The normal length of connecting hose is 25 ft., but up to 50 ft. of additional hose can be used.

The high production gun can be supplied for manual propulsion or, if preferred, power traction can be arranged, the front wheels being fitted with an air motor and reversing gear controlled from the operator's handle, which also carries an on-off control for the blast.

The Senior machine can be supplied either as a single assembly or with the dust collector as a separate unit. If the high production gun is not in use, it is suitable for feeding two standard guns, of which there are several varieties to suit various types of work such as edge cleaning of plates. There is also a Junior model machine which is suitable for single-gun operation.

A comparatively recent development in Vacu-Blast equipment is the new nozzle. Designed to give increased velocity and spread of shot, it is claimed to give 25% more work with the same expenditure of air and shot. The tungsten carbide lining gives a normal working life of 1,000 hours.

It is emphasized by the Vacu-Blast company that they do not claim that their system can show outstanding advantages on any and every job, and it is admitted that many jobs are "marginal" and many are definitely better carried out by conventional methods. They do, however, claim that, on a wide range of work, spectacular savings can be achieved over conventional methods of cleaning, including pickling, scraping, wire-brushing etc., and figures as low as 1d per sq. ft. have been quoted in certain cases.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 751,152. Nuclear reactor. To: Stichting voor Fundamenteel Onderzoek der Materie (Netherlands).

Refers to a heavy water moderated reactor. The moderating properties of heavy water strongly decrease with increasing temperature so that the partition walls between the space for the moderator and the space where nuclear fission occurs should have good heat-insulating capacities without having inadmissibly high neutron absorption capacity. It was found that the desired result could be obtained by coating the walls on the moderator side with a porous material of low neutron absorption capacity. The cavities in this material get filled with heavy water which has the effect of very good heat insulation. Loosely sintered beryllium oxide is suggested as the porous material, the wall itself may be of tightly sintered beryllium oxide.

B.P. 751,441. Method of alloying reactive metals with aluminium or beryllium. To: Atomic Energy of Canada Ltd. (Canada).

It concerns the alloying of neptunium, cerium or americium with aluminium or beryllium. A halide of the reactive metals is mixed with aluminium or beryllium (reducing metals) and the mass heated to between 700 and 1,200°C in a vacuum of about 10^{-3}mm Hg, until the halide of the reactive metal is reduced and the metal itself alloys with the reducing metal.

B.P. 752,940. Method of chemically cleaning the surface of articles of zirconium or hafnium or alloys thereof and of applying adherent electroplates to zirconium or hafnium surfaces or to the surfaces of alloys of these metals. To: United States Atomic Energy Commission (U.S.A.).

It has been found that the metals can be cleaned by etching their surfaces with an aqueous solution of ammonium fluoride and hydrofluoric acid. On the cleaned surface can be electroplated an adherent coating of other metals. The composite article is then heat-treated.

B.P. 753,130. Atomic energy-producing devices. S. G. Bauer, R. E. Newell. To: U.K. Atomic Energy Authority.

Various methods have been suggested to keep a chain reaction stable, i.e., to obtain an exact balance between the total loss of neutrons and the total neutron production. Where a "homogeneous boiler" is used, that is a "nuclear boiler" in which the media are mixed intimately together, a control of the working quantity contained in the boiler is easy. Where a "heterogeneous boiler" is to be used, i.e., in which parts of the system contain a concentration of one medium while other parts contain a concentration of another medium, control of the loss of neutrons could not be carried out in a simple manner. The boiler, according to Fig. 1, shows a simple solution of the control problem. The boiler has an outer (e.g., spherical) shell 9, greater than the critical size at which the chain reaction becomes divergent. Rods 8 of, or containing fissile material are arranged within (thin-walled aluminium) tubes 7 connected at each end to a heater 10, 11, with inlet 12, and outlet 13. The boiler shell 9, is similarly provided with inlet 14, and outlet 15. Heavy water may be used as the moderating medium separated from ordinary water or

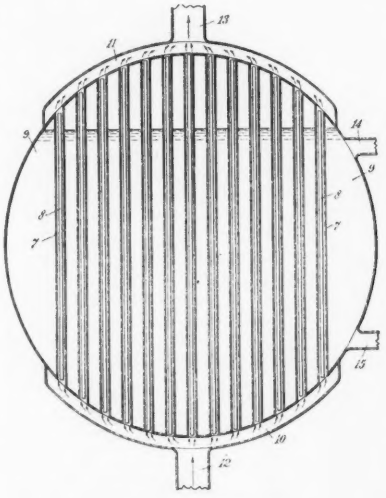


Fig. 1. B.P. 753,130.

vapour used as coolant. It is easy to control the level of the moderator fluid in the boiler while the coolant within the tubes can be circulated past the rods at any desired temperatures and velocities. By passing the moderator in the boiler through a separate cooler, the temperature within the boiler can be kept lower than that of the coolant which means a corresponding reduction in the critical size of the system.

B.P. 753,399. Process of nuclear fission. To: Stichting voor Fundamenteel Onderzoek der Materie (Netherlands).

Refers to thermal and power reactors using natural uranium or enriched uranium (natural uranium to which amounts of U 235, Pu 239 or U 233 have been added) and to the problem of continuous removal of undesirable impurities from the nuclear fuel caused by neutron absorption. The neutron-capturing properties of these impurities have an unfavourable effect on a chain reaction. The problem has been solved by applying the nuclear fuel in the form of a stable suspension, i.e., a dispersion of solid fissile material in a carrier liquid in which no agglomeration of particles occurs. All the suspended particles have a maximum diameter not exceeding 15 microns. It has appeared that the fission products are capable of leaving the fuel particles in the suspension and are slowed down and retained in the carrier liquid so that by separating part of the carrier liquid from the suspension and purifying it, e.g., by ion exchange and/or adsorbents, the fission products can be removed. Those nuclei which are formed by neutron capture and subsequent β-emission (e.g., Pu 239 or U 233) should not be allowed to leave the fuel particles, which means that the suspended particles should have a minimum diameter of 0.01 micron. Suitable suspensions are dispersions of oxides of natural or slightly enriched uranium in heavy water, dispersions of enriched uranyl oxides in natural water, or in natural water enriched with heavy water. Easy separation may be effected in a hydrocyclone thickener if the mean effective diameter of the solid particles is equal to or greater than 1 micron.

B.P. 754,183. Nuclear-chain reactor. To: Allmanna Svenska Elektriska A.B. (Sweden)

A reactor using heavy water as moderator at atmospheric pressure, i.e., at a temperature below 100°C in which uranium (thorium or a mixture of both) is used as fuel in form of hollow rods in (zirconium or aluminium) pipes internally cooled by liquid metal (sodium). The pipes are surrounded by additional pipes leaving a space for decreasing the heat transmission to the heavy water. Fig. 2 shows a container (aluminium), 1 filled with heavy water, 2. The container is connected through 3, 4 to a heat exchanger. 5 are blocks of graphite as neutron reflectors. Plate 6 rests on concrete base 7. The hollow uranium (thorium) rods 8 are inserted with a light fit in (zirconium) pipes 9. The space between pipes 9 and 10 may be evacuated or filled with a protecting gas (helium; carbon dioxide). Fluid metal enters through 13 into distributor 11 and passes to collector 12 and outlet 14. The heat exchanger in which the heat is transmitted to a steam generator is not shown.

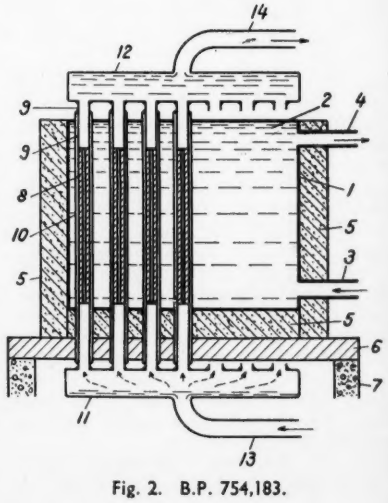


Fig. 2. B.P. 754,183.